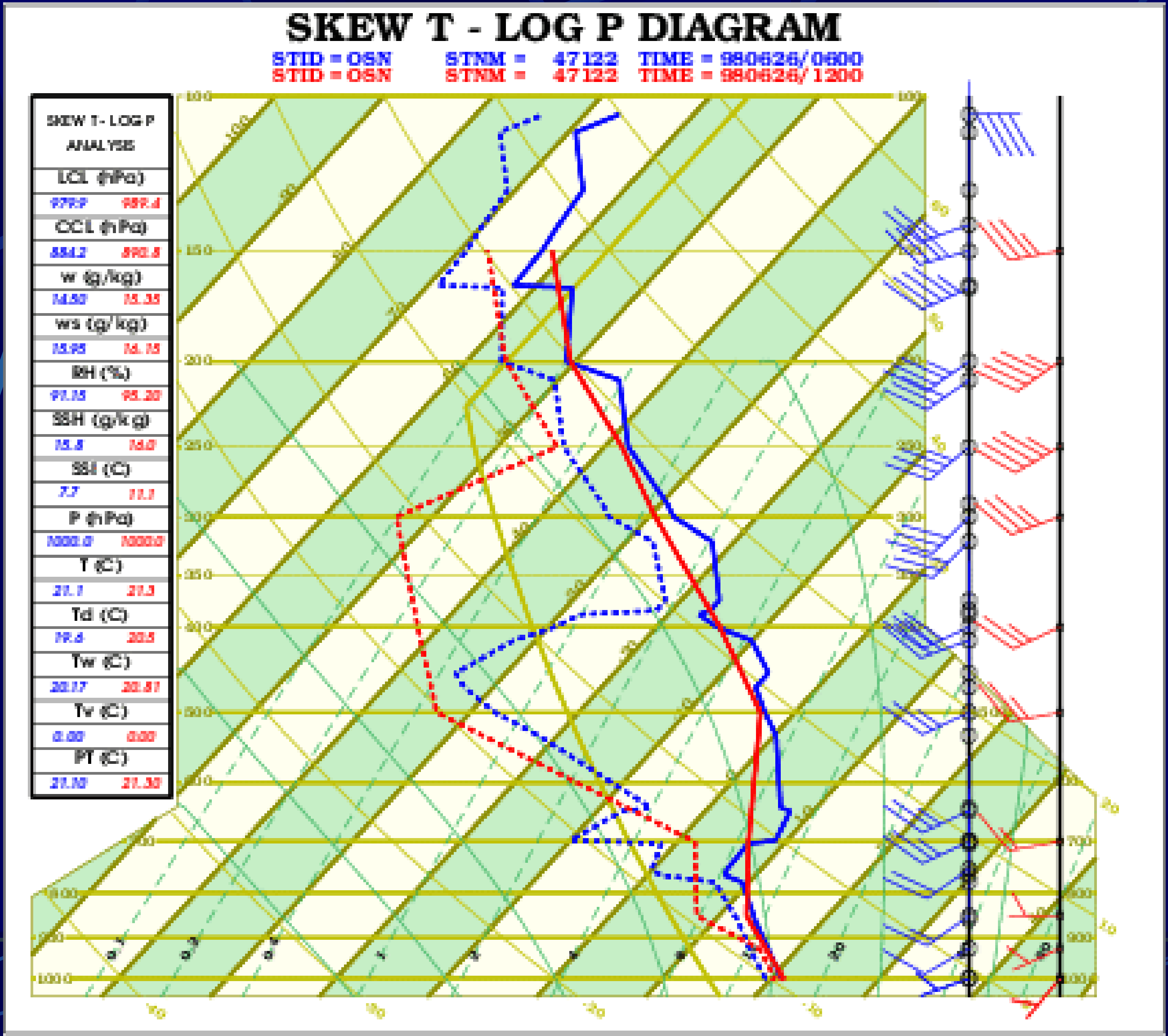
ANALYZING THE SKEW T, LOG P DIAGRAM



OVERVIEW

Identify parameters on the Skew T, Log P Diagram.

Describe the computation procedure to find derived measurements from plotted data on the Skew T.

Describe the computation procedure to find the forecast surface temperatures on the Skew T.

Define and describe computation procedures for

OUTLINE

Skew T parameters
Dry adiabats
Saturation adiabats
Saturation mixing ratio
Thickness scale
Contrail formation curves
U.S. Standard Atmosphere
Computation of derived measurements
Potential temperature
Frost point temperature
Saturation mixing ratio
Actual mixing ratio
Relative humidity
Wet-bulb temperature
Wet-bulb potential temperature
Virtual temperature
Layer thickness
Freezing level
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Maximum temperature
Minimum temperature
Computation of cloud formation parameters on the Skew T
Lifting condensation level (LCL)
Convective condensation level (CCL)
Mixing condensation level (MCL)
Level of free convection (LFC)
Positive energy area (PEA) and negative energy area (NEA)
Equilibrium level (EL)

ANALYZING THE SKEW T, LOG P DIAGRAM

The Skew T, Log P Diagram is a thermo-dynamic diagram on which information obtained from upper-air soundings is plotted and analyzed. Several procedures have been developed that allow rapid graphical computations from data plotted on a Skew T chart. In this lesson we explain the more important parameters of the Skew T diagram, and then cover the more frequently used computations that you will need to know to analyze the Skew T. These procedures include computations of derived measurements, cloud formation parameters, expected temperatures, cloud layer criteria, convective weather guidelines, indices for severe weather, contrail formation guidelines, the freezing level, and icing. We will also discuss frontal analysis on the Skew T. Before going on, you should review Unit 3-Lesson 3 of the AG3 training manual for plotting procedures and AG2, *Volume 2,* Unit 2 - Lesson 4, for stability theory. Note: The figures referred to in the text are in black and white, while the Skew T diagram is printed in black, brown, light green, and dark green. You may wish to obtain an actual Skew T, Log P Diagram (DOD WPC 9-16) in order to follow the text more accurately.

Learning Objective:

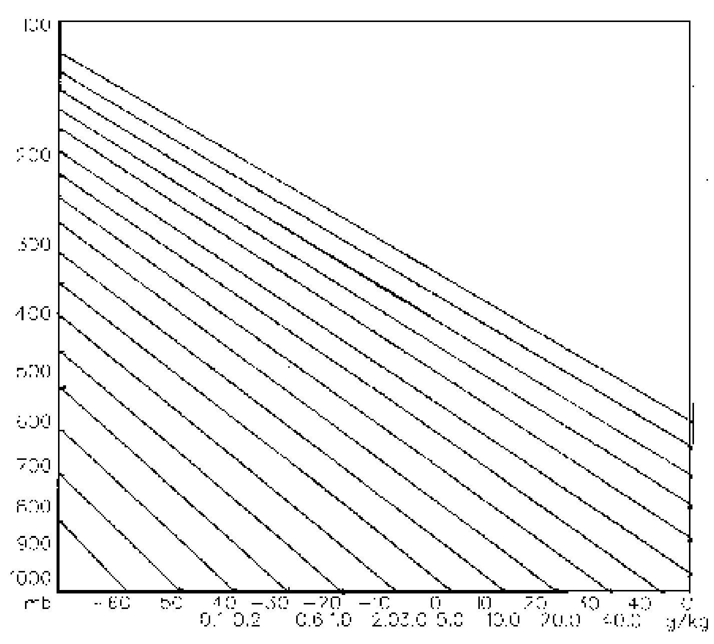
Identify parameters of the Skew T, Log P Diagram.

SKEW T PARAMETERS

The Skew T diagram represents a graphical presentation of the relationship between many parameters in the thermodynamic equation. In the AG3 manual you studied the isobars, isotherms, height scales, and wind scale, while learning to plot the temperature curve, dew point curve, pressure altitude curve, and wind reports. Now you need to learn what the other lines are and how to use them.

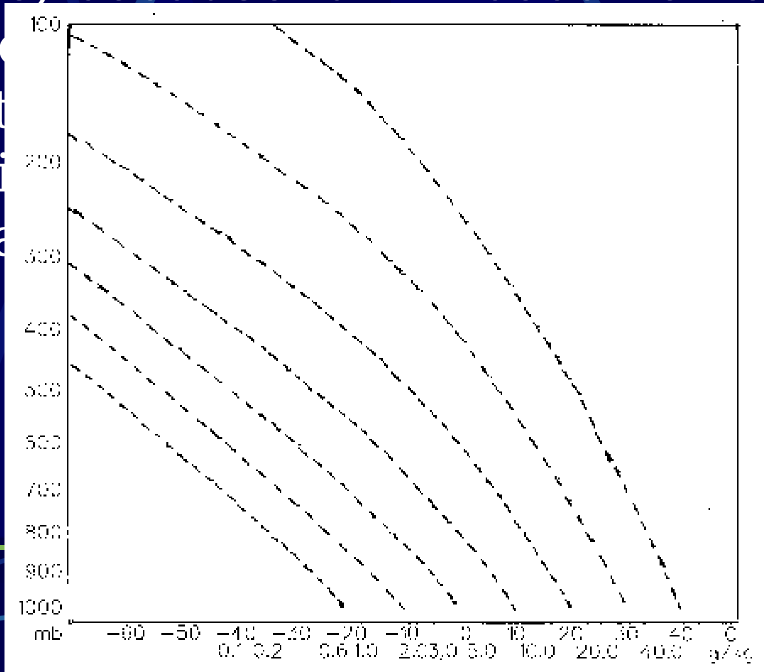
Dry Adiabats

The *dry adiabats* represent the rate at which nonsaturated air will cool as it moves upward, or warm as it moves downward in the atmosphere. This rate of cooling or warming is called the dry adiabatic lapse rate. On the diagram, the dry adiabats are drawn as thin, slightly curved brown lines extending diagonally upward from right to left. These lines have a spacing, or interval, of 2°C, and are labeled across the top, bottom, and along the sides of the chart in diagonal bold brown numbers. The light brown numbers within parentheses below the bold numbers at the top of the diagram are the values for the dry adiabats in the 100- to 25-millibar pressure range. The values [...] e isotherms are the same at the 1,000- [...] es represent potential temperature in de[...]



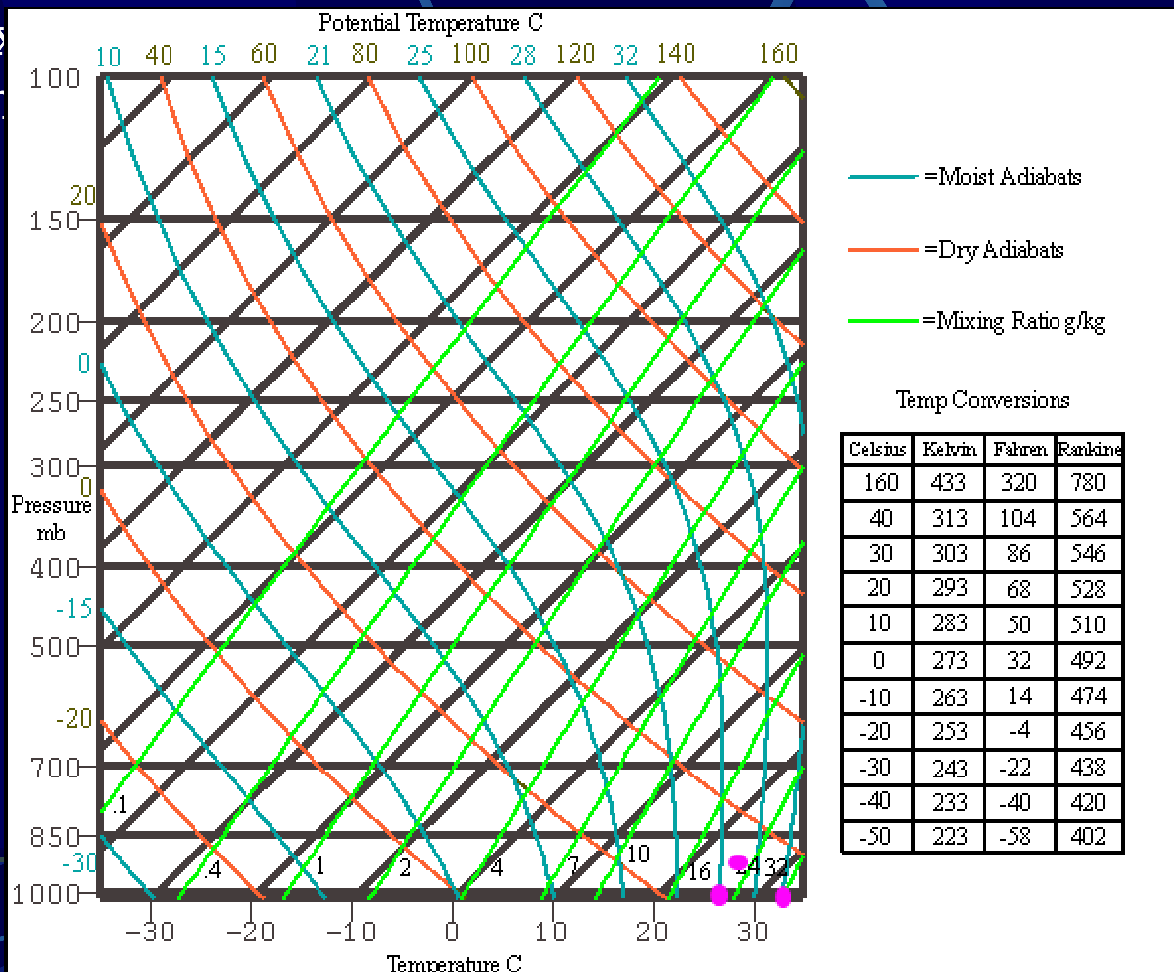
Saturation Adiabats

The *saturation adiabats* are the curved green lines that intersect the 1,000-millibar isobar at 2°C intervals. These lines curve upward toward the left and diverge as they get closer to the top of the diagram. They terminate at the 200-millibar level and are labeled at that point in green numbers. The values can also be read at the 1,000-millibar level, where they are the same as the value of the intersecting isotherms. These lines represent the rate at which a saturated parcel of air will cool as it moves upward in the atmosphere. Saturated air will not warm at this rate as it moves downward in the atmosphere, because it will become nonsaturated the moment it begins to desc ases. The difference in the dry adiabat lapse rates is the *heat of condensation* gai vapor condenses out of saturated a



Saturation Mixing Ratio

The dashed green lines extending from the bottom of the diagram upward diagonally toward the right are the *saturation mixing ratio* lines. They are labeled near the bottom of the diagram in green numbers representing grams of water per kilogram of air. We use the mixing ratio lines later to find how much moisture is in the air (actual mix … an hold (saturation …



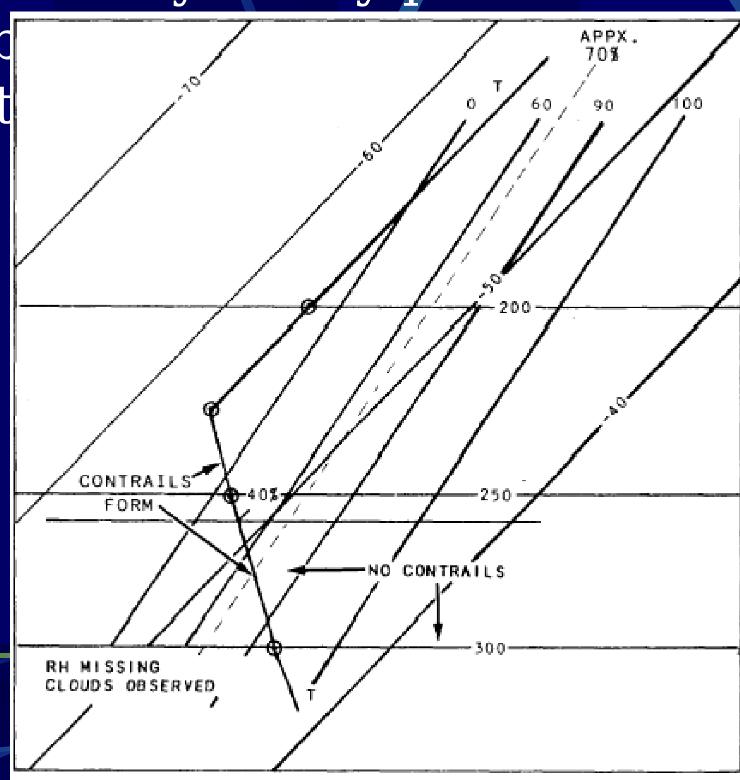
Celsius	Kelvin	Fahren	Rankine
160	433	320	780
40	313	104	564
30	303	86	546
20	293	68	528
10	283	50	510
0	273	32	492
-10	263	14	474
-20	253	-4	456
-30	243	-22	438
-40	233	-40	420
-50	223	-58	402

Thickness Scale

Ten horizontal scales printed in black extend across the central portion of the diagram parallel to the isobars. These are the thickness scales. Each is labeled on the left side by two numbers separated by a solidus, such as the 1000/700 we find on the bottommost scale near the 840-millibar isobar. They are graduated, with increments being in feet above the horizontal line and in meters below the horizontal line. The graduations are labeled in hundreds of feet and in hundreds of meters. These scales are used to calculate the thickness of the layer of the atmosphere between the two values. We would use the bottom scale to calculate the thickness of the 1,000-millibar to 700-millibar layer, for instance.

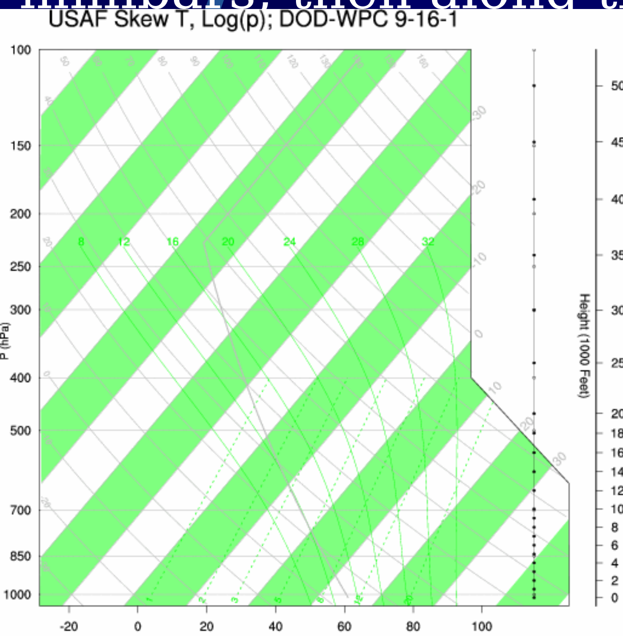
Contrail Formation Scale

At the 500-millibar isobar between the –36 degree and –47 degree isotherms are four fine black lines extending upward to the right all the way to the top of the diagram. At the 400-millibar isobar (which is also the 100-millibar isobar) are four dashed black lines extending upward to the right, ending at the 40-millibar level. These are the *contrail formation scales* for the 500-millibar to 100-millibar and 100-millibar to 40-millibar levels. They are labeled from right to left as 100, 90, 60, and 0. The lines indicate the temperature and relative humidity necessary at any pressure above 500 millibars for saturation to occur b … or from a jet aircraft engine. We will use t … rail formation levels.



U.S. Standard Atmosphere

The *U.S. Standard Atmosphere is* a representation of an ideal atmosphere based on the thermodynamic equation and the defined standards for sea level pressure (29.921 inches of mercury) and sea level temperature (59.0°F). It is not a climatological average for the continental United States. The temperatures of the standard atmosphere are plotted as a single brown line extending from the bottom of the chart at the 17°C isotherm upward to the left to 256 millibars, then along the –56.5°C isotherm to the 100-millibar level.
printed in both meters and feet on the left side
the standard pressure levels, as well as on a
e diagram.



Learning Objective:

Describe the computation procedure to find derived measurements from plotted data on the Skew T, Log P

COMPUTATION OF DERIVED MEASUREMENTS

Now that you understand what all those strange looking lines represent, we can use the plotted temperature, dew point, and height data to find some additional data measurements. This data normally would be calculated using complex formulas from the reported data. On the Skew T, we simply follow the correct lines to find the values. We will derive measurements for the potential temperature, frost point temperature, saturation mixing ratio, actual mixing ratio, relative humidity, wet-bulb temperature, wet-bulb potential temperature, virtual temperature, and layer thickness in this manner.

Potential Temperature

Potential temperature is the temperature a parcel of air can attain if it descends dry adiabatically to the 1,000-millibar level. Since the dry adiabats are labeled in degrees Celsius and coincide with the isotherms at the 1,000-millibar level, we can see that the dry adiabats actually are potential temperature lines. To find the potential temperature of a parcel of air, interpolate the value of the plotted temperature by using the dry adiabats closest to the temperature plot. You may find it easier to read the value by drawing a light pencil line parallel to the dry adiabats either upward to the top of the diagram where the values are printed or downward to the

Frost Point Temperature

Frost point is the temperature to which air has to be cooled to reach saturation with respect to ice. The frost point is always warmer than the dew point below zero degrees Celsius. An approximation of the frost point [illegible] formula

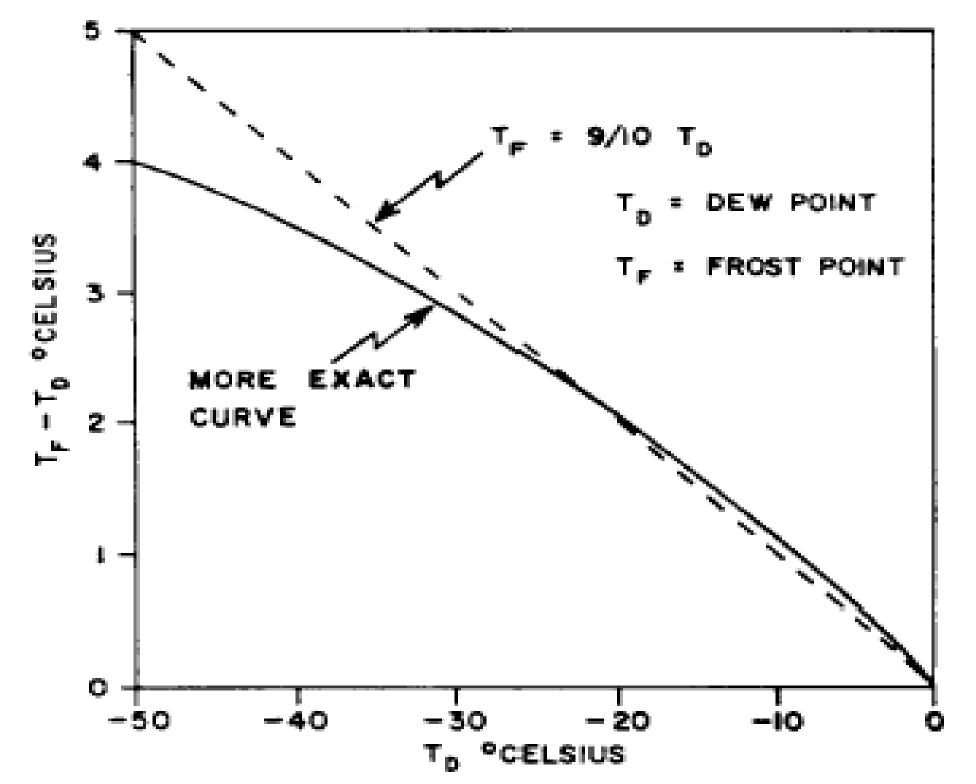
$$T_F = \frac{9}{10} T_D,$$

where T_F = frost point temperature and T_D = dew point temperature.

While this formula does not yield an exact frost point temperature, it is quickly and easily computed.

The frost point temperature should be computed and plotted for all levels above the point where the air temperature crosses the 0°C isotherm. This is especially important when analyzing the Skew T for cloud layers. The frost point curve will fall between the temperature and the dew point curve unless the cloud is super-saturated with respect to ice. In this case, the frost point curve will cross to the right of the temperature curve.

In clouds with temperatures above freezing, the true dew point will coincide closely with the true temperature, indicating that the air between the cloud droplets is practically saturated with respect to the water surface of the droplets. Minor discrepancies may exist when the cloud is not in a state of equilibrium (when the cloud is forming or dissolving rapidly), or when precipitation is falling through the cloud with temperatures slightly different from the air temperature. These differences are small theoretically. In the sub-freezing part of the cloud, the true temperature at which condensation occurs will fall between the frost point temperature and the dew point temperature. If the cloud consists entirely of supercooled water droplets, this temperature will be the same as the dew point temperature. If the cloud is made entirely of ice crystals, the frost point will coincide with the true condensation temperature, which means that the moisture is changing directly from water vapor into ice crystals through sublimation. Below – 12°C, most clouds form through the sublimation of water vapor directly into ice crystals.



We may state, as a general rule, that clouds below -12°C are saturated with respect to ice; therefore, the moisture content should be evaluated by use of the frost point temperature. Above freezing, clouds are generally saturated with respect to water, and the dew point temperature should be used to evaluate the moisture content. Between the freezing point and –12°C, clouds may be saturated with respect to water or to ice, or somewhere between the two values if a cloud is mixed ice and water. In the last case, the moisture content should be evaluated using both the dew point and frost point temperatures. Supersaturation with respect to ice, as indicated by

Saturation Mixing Ratio

Saturation mixing ratio (W_s) is the theoretical maximum amount of water vapor that air at a specific temperature and pressure can hold. When air is saturated, it cannot hold any additional water vapor. To find this value at any pressure level, use the dashed green saturation mixing ratio lines on either side of your plotted temperature. Interpolate the value of your temperature plot using the scale on the mixing ratio lines printed just above the 1,000-millibar level. For instance, if your 500-millibar temperature is –15.6°C, this falls halfway between the green dashed lines labeled 2.5 and 2.0, you would interpolate the value to be 2.25. Since these lines represent grams of water per kilogram of air, you know that a parcel of saturated air with a pressure of 500 millibars and a temperature of 15.6°C can hold 2.25 grams of water vapor per kilogram of air.

Actual Mixing Ratio

To find the *actual mixing ratio (W),* often called simply the mixing ratio, interpolate the value of the same dashed green lines at the plotted dew point temperature for temperatures above freezing and down to -12°C. For levels where the air temperature is below freezing, evaluate the value of the mixing ratio line through your calculated frost point temperature. You will have two sets of values in the 0°C to -12°C range. For levels where the air temperature is below -12°C, you need only evaluate the mixing ratio through the frost point temperature. When we do this, we find how much water vapor is held by a parcel of air at the specified pressure level. For example, if your 800-millibar temperature is 5.0°C and your dew point temperature is 3.0°C, you should read the value of your mixing ratio line through the dew point temperature as 6.0 grams of water per kilogram of dry air (or simply 6.0 g/kg). But let's look at a case where your temperature is between 0°C and -12°C. Say your 600-millibar temperature is – 10.0°C and the dew point temperature is – 15.0°C. You should first calculate a frost point temperature. In this case, it is – 13.5°C. Now evaluate the mixing ratio through both the dew point temperature and the frost point temperature. You should find a value of 2.0 g/kg for the dew point temperature and 2.25 g/kg for the frost point temperature. In the next section we will use this

Now that you know how to find the saturation mixing ratio and the actual mixing ratio, what do you do with them? Let's find out.

Relative Humidity

Relative humidity is a ratio, expressed in percent, of the amount of water vapor in the air (actual mixing ratio) compared to the amount of water vapor the air can hold (saturation mixing ratio). Since we have already found these values, we can find the relative humidity for any plotted pressure level by using the formula

$$RH = \frac{W}{W_s} \times 100,$$

where RH = relative humidity, in percent;

W = actual mixing ratio; and

W_s = saturation mixing ratio.

Since the units (grams per kilogram) cancel, we are left with a number, expressed as a percentage.

Wet-bulb Temperature

Wet-bulb temperature (T_W) is the lowest temperature to which air can be cooled by the evaporation of water into the air at a constant pressure. Of course, the heat required for evaporation is supplied by the air. This is called the heat of vaporization. During this process, the air is cooled. The wet-bulb temperature is found by a graphical process on the Skew T, as follows:

1. From the dew point temperature, draw a line upward parallel to the mixing ratio lines.
2. From the temperature, draw a line upward parallel to the dry adiabats.
3. From the point where these two lines intersect, draw a line downward parallel to the moist adiabats to intersect the original pressure level. The temperature at the point of intersection is the wet-bulb temperature. See figure 6-2-2 for an example of the wet-bulb temperature procedure.

When constructing a wet-bulb-temperature curve, plot the wet-bulb temperatures in green. You may evaluate all plotted pressure levels up to the dew point cutoff, then connect the wet-bulb temperatures by a green line to draw the curve. In practice, the *Wet-bulb-Zero* (WBZ) height is the only data routinely used. The WBZ is the level at which the wet-bulb temperature crosses the 0°C isotherm. This can be found by constructing the wet-bulb curve only in the area where

Wet-bulb Potential Temperature

Wet-bulb potential temperature (T_θ) is the wet-bulb temperature a parcel of air would have if the parcel descended to 1,000 millibars. To find the wet-bulb potential temperature, simply read the values for the closest saturation adiabats. You may find it easier to read the values by drawing a light pencil line from the wet-bulb temperature parallel to the saturation adiabats to either the 1,000-millibar level or the 200-millibar level. Interpolate if necessary. See figure 6-2-2 for an example.

Virtual Temperature

Virtual temperature (T_V) of a parcel of air is a derived value based on the air temperature and the water content of the air. The virtual temperature can be appr

$$T_V = T + \frac{W}{6},$$

where T_V = virtual temperature at a pressure level,

T = temperature at the pressure level, and

W = actual mixing ratio at the pressure level.

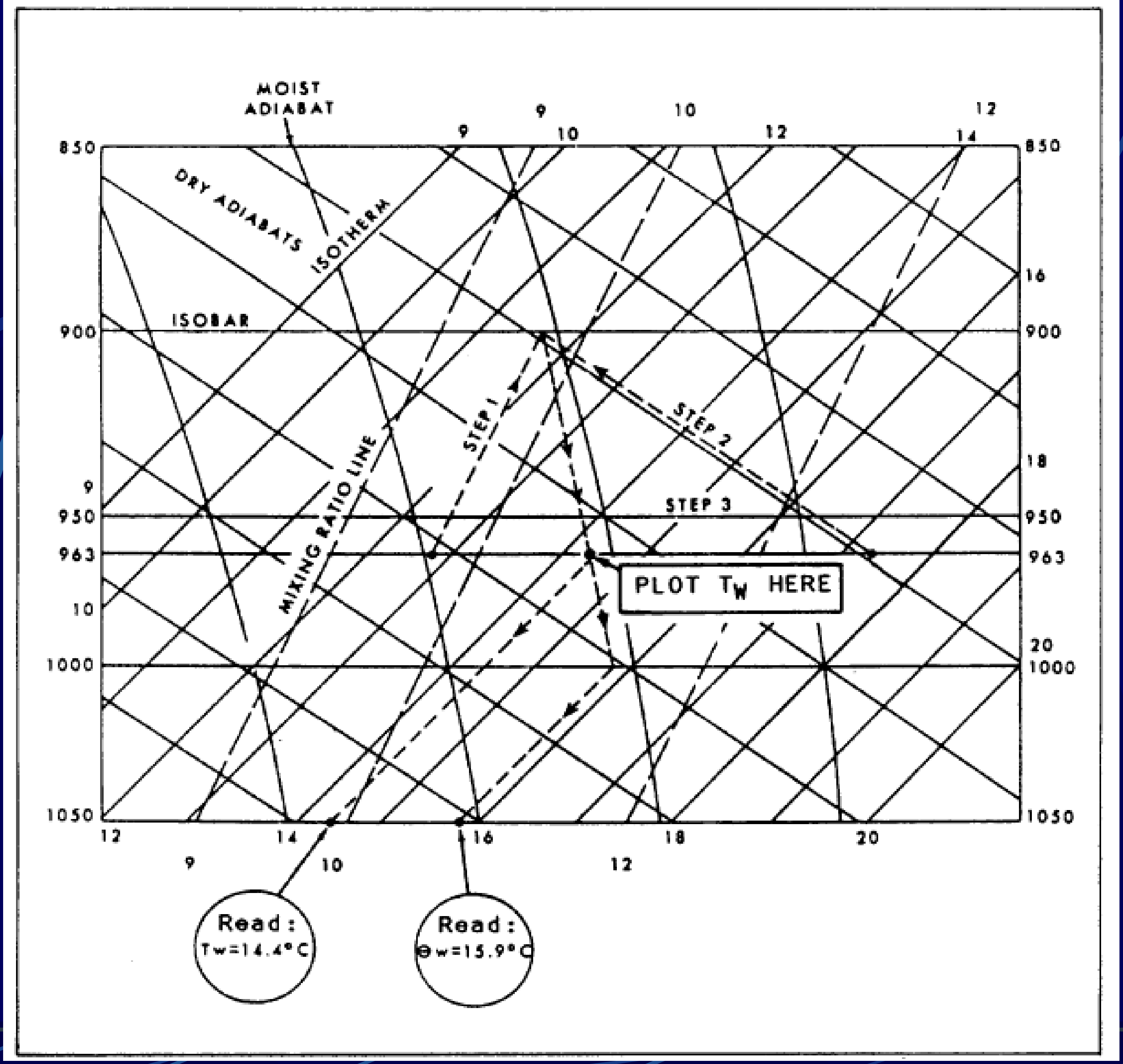
For example, suppose we have a plotted report at 700 millibars with a temperature of -5°C and a dew point temperature of –7.9°C. Reading the mixing ratio at the dew point temperature would give us an actual mixing ratio *(W)* of 3.0 g ram. Using the formula, we would find the followi

$$T_V = T + \frac{W}{6}$$

$$T_V = -5\,^{\circ}\mathrm{C} + \frac{3\ \mathrm{g/kg}}{6\ \mathrm{g/kg}}$$

$$T_V = -4.5\,^{\circ}\mathrm{C}$$

Repeating these calculations for all temperature levels, plotting the values in pencil, and connecting the plots will yield a virtual temperature curve. If plotted, this curve will always be to the right of the actual temperature curve. Where the air is dry, the virtual temperature curve will be plotted just about over the actual



Wet-bulb temperature and potential temperature.

Layer Thickness Computation

Layer thickness, or the depth through a layer, is used by the forecaster to determine the type of precipitation expected, as well as several other forecast evaluations. The thickness of a layer is a function of the temperature and the moisture content. The warmer the air through a layer, the thicker the layer. The thickness scales are printed on the Skew T for the standard layers routinely evaluated. To compute layer thickness on plotted Skew T, follow these steps:

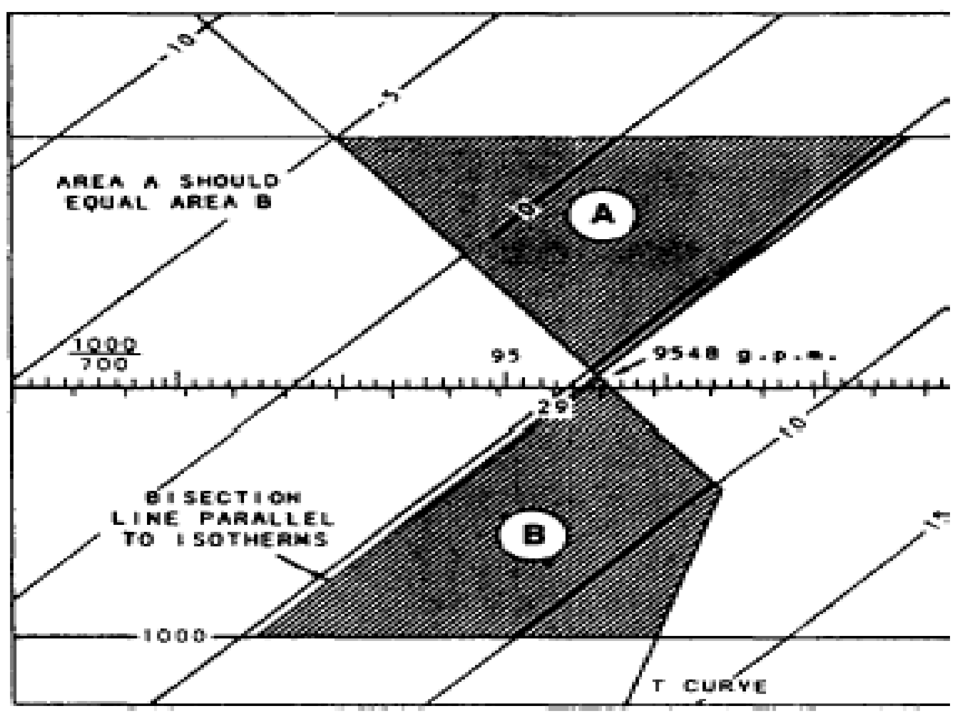
1. Determine if the dew point curve through the layer indicates an average moisture greater than 3 g/kg.

a. If the average moisture is greater than 3 g/kg, the virtual temperature curve should be constructed for the layer.

b. If the average moisture is less than 3 g/kg, the difference between the virtual temperature curve and the actual temperature curve will be very slight, and the actual temperature curve may be used in place of a virtual temperature curve.

2. Bisect the virtual temperature curve (or actual temperature curve) through the layer with a vertical line so the area enclosed by your vertical line, the upper and lower isobars, and the temperature curve is approximately equal. See figure next slide.

3. Read the layer thickness where your vertical line intersects the



Freezing Level

Freezing level is the height, or heights, in the atmosphere where the temperature falls below the freezing point of water. Finding it is a fairly straightforward process. Follow the plotted temperature curve up until you intersect the 0°C isotherm. If your temperature curve is progressing from warmer to colder temperatures, you have a freezing level. Determine the height of this pressure level using the pressure-altitude curve. There may be more than one freezing level above a station at any one time.

Learning Objective:

Describe the computation procedure used to find the forecast surface temperatures on the Skew T.

COMPUTATION OF PREDICTED SURFACE TEMPERATURES ON THE SKEW T

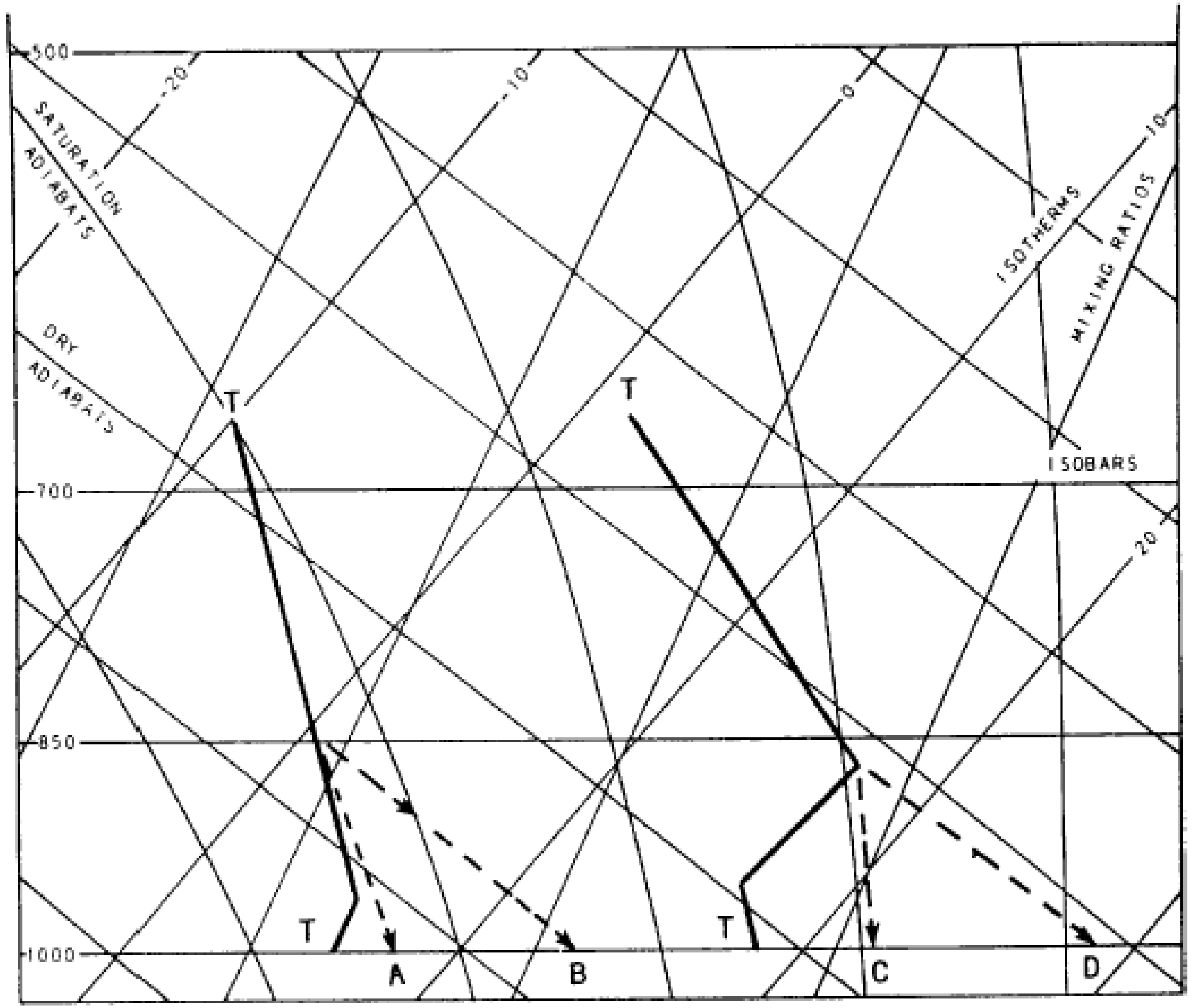
While forecasting maximum and minimum temperatures for your station or location is obviously a job for the forecaster, proper analysis of the Skew T may give the forecaster a computed value for both the expected maximum and the expected minimum temperatures. Forecasters commonly use these computed values as one of several inputs for their temperature forecast. A major limitation of both techniques that we will discuss is that they are only valid for predicting the temperature within an air mass. If a frontal passage is expected between the time of the morning sounding and the time of the expected maximum temperature that afternoon or the time of the expected minimum temperature the following morning, these techniques should not be used. Another limitation is that the forecaster should routinely forecast temperatures out to 48 hours for any location and out to 5 days for stateside locations, while these techniques only provide predictions out to 24 hours.

Maximum Temperature

Calculations for the maximum temperature on the Skew T should be done using the early morning, or cool, sounding for the day. For continental United States locations, this is normally done with the 1200Z plotted on a Skew T. Of course, many of us are not stationed in CONUS, and we have to use the available sounding that comes closest to the coolest part of the day, during the period near sunrise. In order to calculate the maximum expected temperature for the day, you must first determine if the day will be cloudy, with little solar insolation received at the surface, or sunny, with a great deal of solar insolation received at the surface.

Analysis of the current clouds and expected cloud development on the Skew T should provide this information, or consult the forecaster. If the day is expected to be mostly sunny, follow a dry adiabat from your 850-millibar temperature to the surface pressure level and read the temperature at the intersection. For mountainous areas and high elevations, you should adjust the procedure to start at a pressure level about 5,000 feet above the surface. If the day is expected to be mostly cloudy (broken cloud cover to overcast), follow a saturation adiabat from the 850-millibar level (or 5,000-foot AGL pressure level) to the surface pressure level and read the temperature at the intersection. See figure 6-2-4 for examples of the maximum temperature computations for sunny and cloudy conditions.

In summer air mass situations, strong radia-tion inversions routinely develop. If your plotted morning Skew T shows a radiation inversion with a top between 4,000 and 6,000 feet, you should use the temperature at the top of the inversion (the warmest point in the inversion) as the starting point in the computation, instead of the 850-millibar temperature.



Computation of maximum temperature; with no inversion 4,000 to 6,000 feet and (A) mostly cloudy skies (B) mostly clear skies; with an inversion between 4,000 to 6,000 feet and (C) mostly cloudy skies (D)

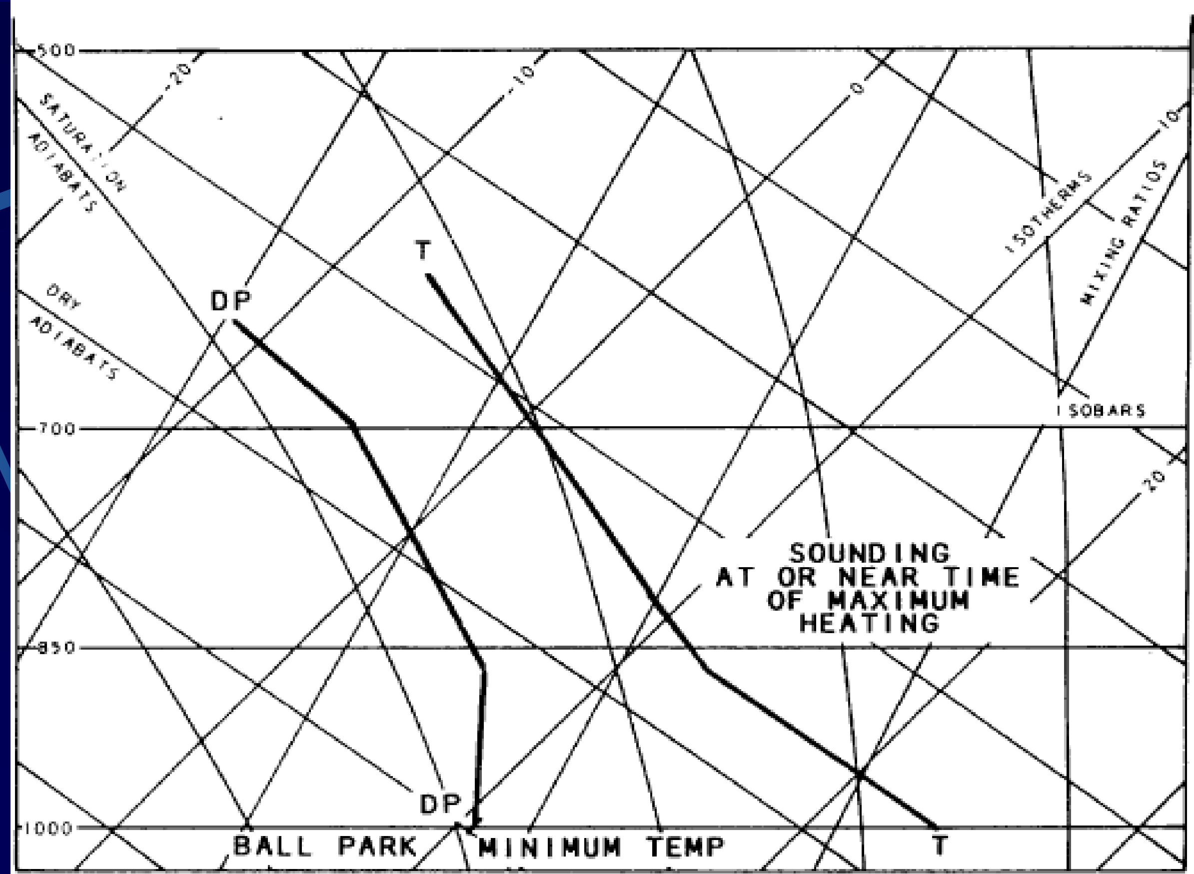
Minimum Temperature

Minimum temperature computations on the Skew T are not as reliable as maximum temperature computations on the Skew T. Many locations have developed methods using the Skew T that work well at one location but are not even close for a different location. Use locally derived procedures for your station if available. Otherwise, two methods for calculating minimum temperatures work fairly well at many locations. You may use either or both methods to find at least a ballpark value for the expected minimum temperature.

The first method uses the early morning sounding to predict a minimum temperature for the following morning. Essentially, this is a 24-hour forecast. From the 850-millibar dew point temperature, follow a saturation adiabat to the current surface pressure level and read the temperature. An example is shown on the next slide. The write-up on this procedure does not mention an adjustment for high elevations, but if you are stationed at a high elevation, you may wish to experiment by using the dew point temperature at 5,000 feet.

A second technique does not actually require the use of the Skew T, although an after-noon sounding conducted near or at the time of maximum heating may be used. In this technique, the dew point temperature at the time of maximum heating is used as the estimate

Computation of minimum temperature.



We have just briefly described two procedures that may be used on the Skew T to compute maximum and minimum temperatures. I must stress that these values are just one input for a proper and accurate temperature forecast, and should not be used without careful forecaster consideration of climatology, numerical forecasts, advection, and other important atmospheric modifiers, which you will study in *AG1&C*.

Learning Objective:

Define the use of and describe the computation procedures for cloud formation parameter analysis on the Skew T, Log P

COMPUTATION OF CLOUD FORMATION PARAMETERS

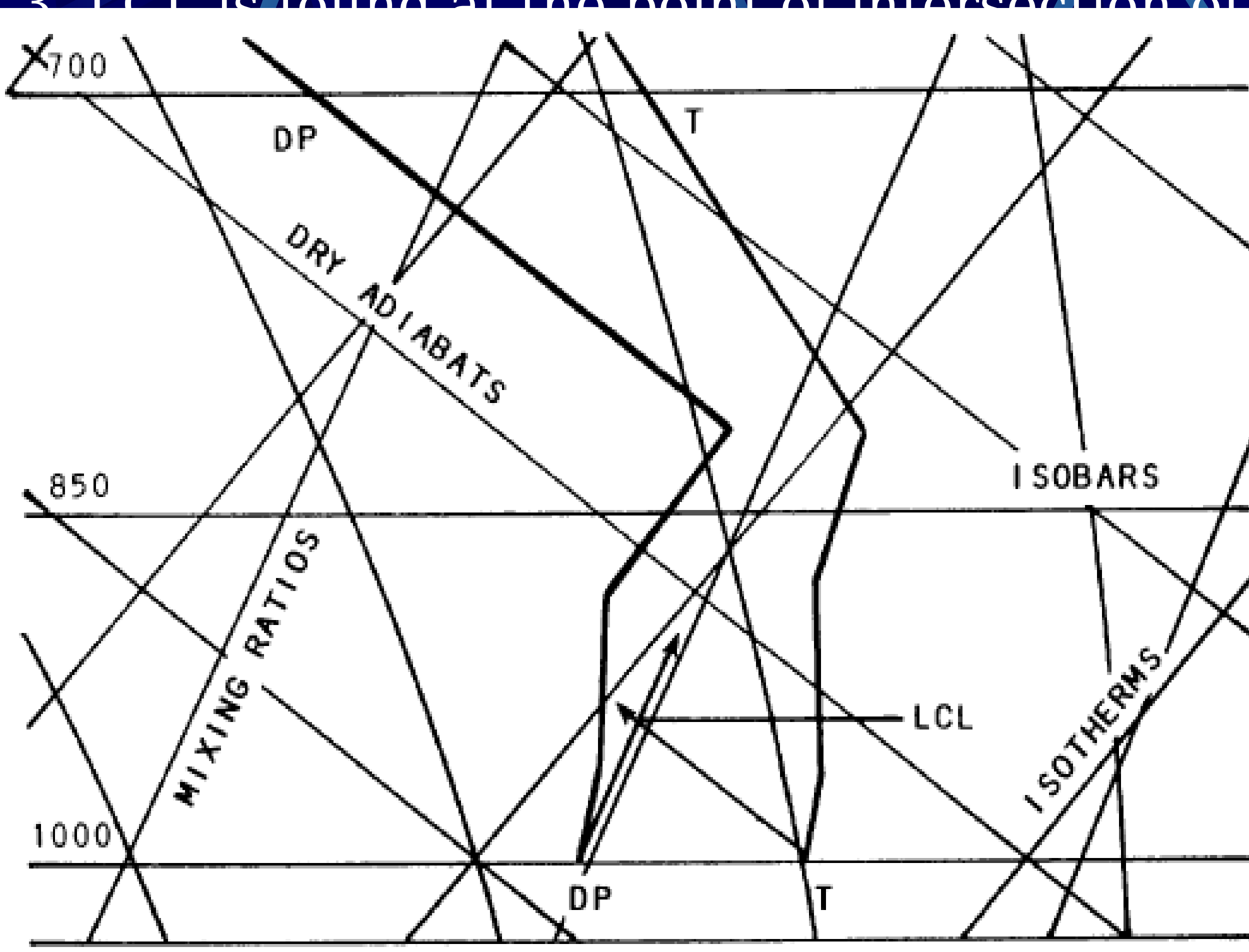
Several graphical and mathematical computations using the data plotted on a Skew T will let us determine where clouds may form if certain conditions are met. In this section, we will look at the levels where we may expect cloud bases to form and the levels where we expect them to end.

Lifting Condensation Level (LCL)

Lifting Condensation Level (LCL) is the height at which a parcel of moist air becomes saturated when "lifted" dry adiabatically. The lifting is brought about by air being forced up (lifted over) frontal and orographic (hilly and mountainous) surfaces. Use this level for your estimate of cloud bases caused by mechanical lifting.

LCL is computed using the surface temperature and dew point. The computation is as follows:

1. From the surface temperature, draw a line upwards parallel to the closest dry adiabat.
2. From the surface dew point, draw a line upwards parallel to the nearest mixing-ratio line.
3. LCL is found at the point of intersection of the two lines. See

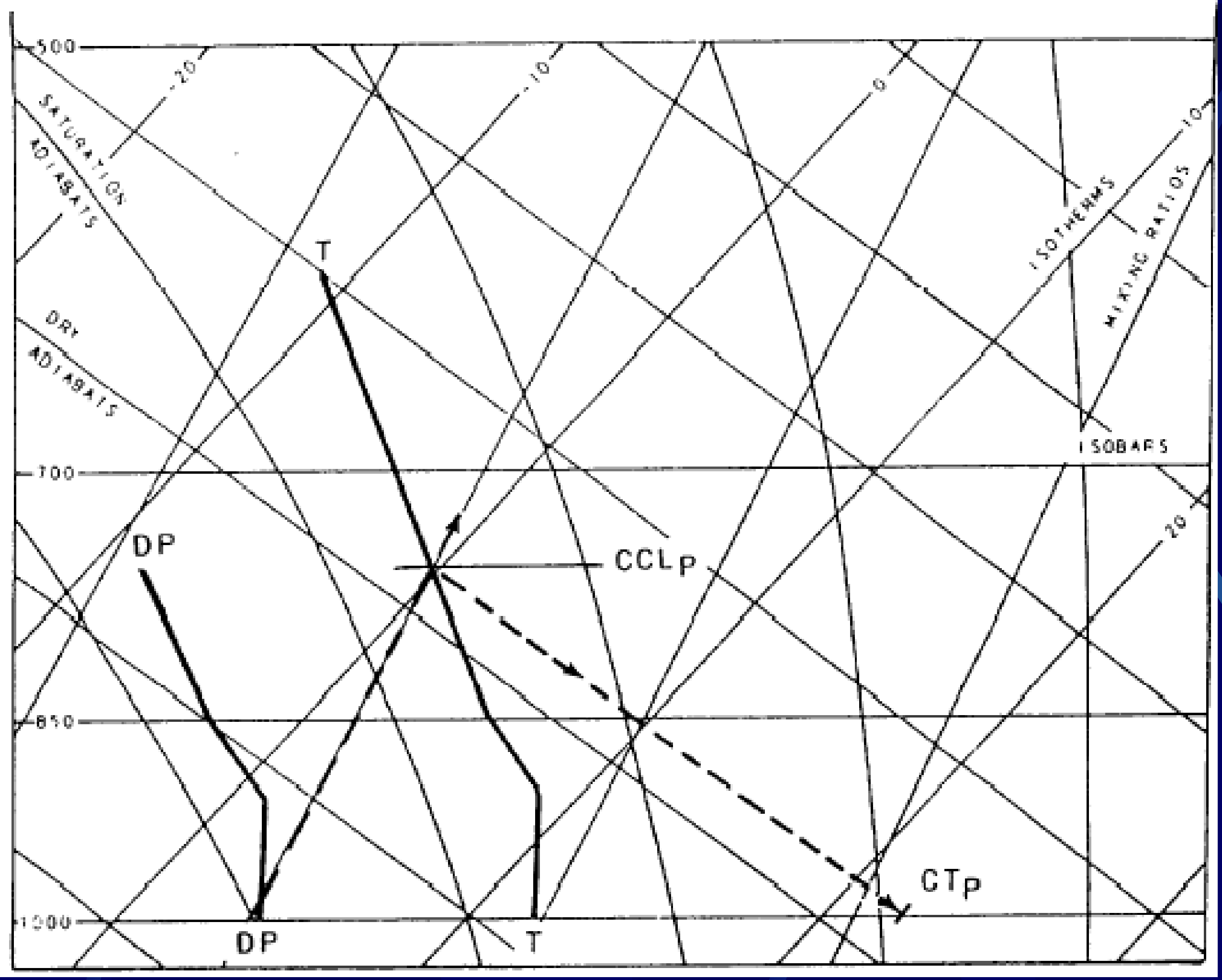


Determination of the lifting condensation level

Convective Condensation Level (CCL) and Convective Temperature (CT)

Convective Condensation Level (CCL) is the height at which a parcel of air, when heated sufficiently from below, rises and becomes saturated. It is where newly forming convective clouds should form bases. There are two methods used to find CCL. One method uses the surface dew point to find CCL. This is known as the parcel method because it evaluates a parcel of air near the surface. It is commonly designated CCL_{P} The second method evaluates CCL using the moist layer near the surface and is known as the moist-layer method, designated CCL_{ME} The parcel method works well when predicting the bases of ordinary cumulus clouds, while the moist-layer method is preferred when predicting thunderstorms and associated phenomena. Both should be evaluated when analyzing the Skew-T.

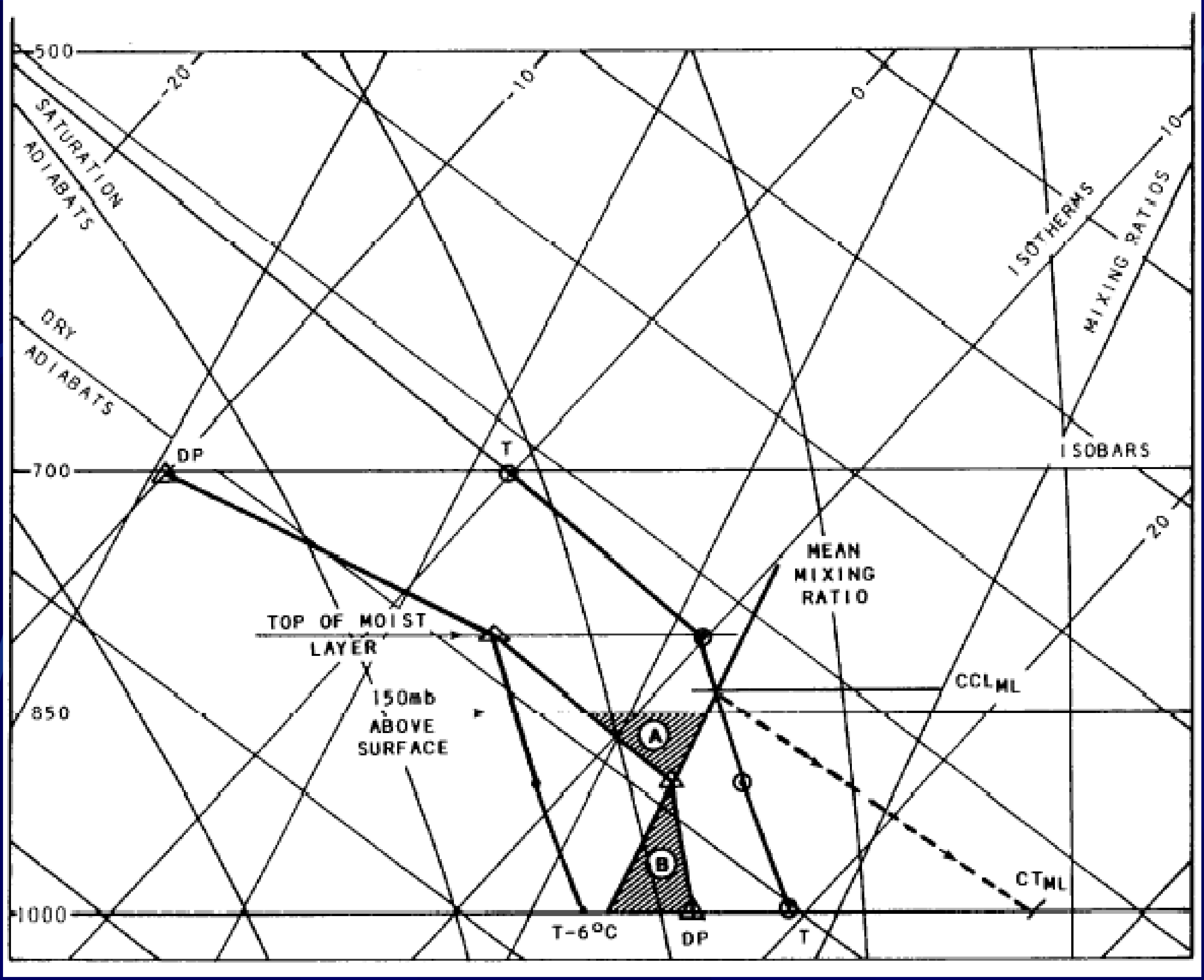
To determine CCL_{P} draw a line upwards from the surface dew point parallel to the nearest saturation mixing ratio line until your line intersects the plotted temperature curve. This is CCL_{P} See figure next slide.



Convective condensation level and convective temperature by the parcel method.

Now that we have determined CCL_P we can very quickly calculate the temperature the surface must reach if clouds are to form at CCL_P. This is the *Convective Temperature (parcel method)* CT_P Once a parcel of air near the surface has heated to this temperature, it will rise to its condensation level without ever being colder than the surrounding air. The CT is found by proceeding from CCL dry

Finding CCL_{ML} is a little more complex. Draw a light line parallel to the temperature curve 6°C cooler than the temperatures on the lowest 150 millibars of your sounding. Your line represents a dew point depression roughly equivalent to 65 percent relative humidity. The area where the dew point curve is to the right of your line is considered a moist layer. Now, bisect the dew point curve in the moist layer, or the dew point curve in the lower 150 millibars if the moist layer exceeds the must reach if clouds are to form at This lower 150 millibars, with a mixing ratio line. The level where this mixing ratio line crosses the temperature curve is CCL_{ML} See figure 6-2-8 for an example of CCL_{ML} Note that in figure 6-2-7 insufficient moisture is present to find CCL_{ML} When insufficient moisture is present, it should be noted in the analysis block of the Skew T. Although cumulus clouds may form during the day if the temperature increases sufficiently, there is not enough moisture present to, form cumulonimbus clouds.



Convective condensation level and convective temperature by the moist-layer method.

Mixing Condensation Level

Mixing Condensation Level (MCL) is the lowest height at which saturation may occur if the near surface layer is or will be mixed completely by wind action. You may relate this to a situation in which you have a radiation inversion keeping the boundary layer wind away from the surface. Mixing is occurring at the top of the inversion. When the radiation inversion breaks, the boundary winds will reach the surface, and mixing will take place through the layer formerly protected from the turbulent winds by the inversion. Before we proceed, let’s look at what occurs in the atmosphere when mixing occurs, and how this is different from convection. Mixing occurs in a layer when vertical wind speed shear or vertical direction wind shear occurs. As was discussed in the previous lesson, shear causes turbulence due to updrafts and downdrafts. These updrafts and downdrafts produce the mixing action.

When mixing occurs, the air in the downdrafts warms dry adiabatically; in an updraft it cools dry adiabatically until saturation is reached, then it cools saturation (moist) adiabatically. The air in the layer tends to become more unstable due to warming in the lower levels if saturation is reached within the layer. The moisture present in a layer tends to become evenly distributed through the mixed layer. The mean mixing ratio line through the layer before mixing closely approximates the dew point curve through a layer after mixing. In the horizontal, we can expect to see relatively equal relative humidity percentages. In the convective-cloud formation process, we find columns of rising air that become saturated and form clouds. Relative humidity in a horizontal layer in this case would show large changes between cloud columns and the ambient air. Since the moisture in a mixed layer is evenly distributed throughout the layer, we do not expect to see scattered clouds forming. Instead, we expect saturation to be reached at the same level throughout the mixed layer. The turbulent process will cause small, relatively evenly spaced areas where downdrafts are occurring where the humidity is slightly lower. Because of this, clouds formed in mixing layers are strato-cumuloform. You will find that mixing layers, when approaching saturation, progress from clear skies to thin broken to overcast layers to dense overcast

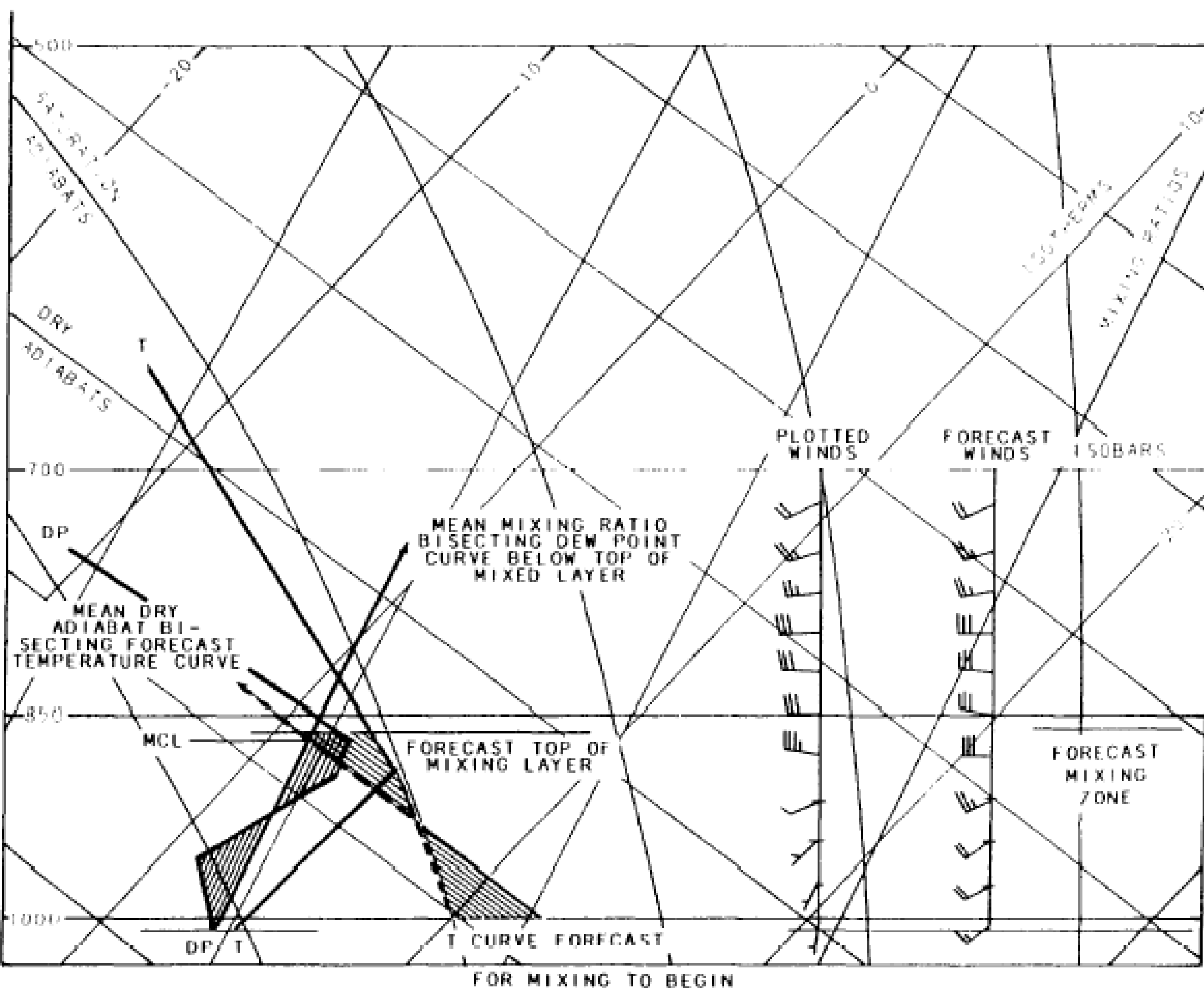
Now that we understand what happens in a layer when mixing occurs, we can see that computation of a MCL on an analysis is useless. Mixing will not begin to occur in your air mass unless certain changes occur. The changes that need to occur for mixing to begin must be forecast. If the mixing process is expected because of increasing wind speeds with a frontal passage, the forecaster must first adjust the lower dew point and temperature curves to reflect the changes expected with frontal passage. If mixing is expected to occur after a radiation inversion breaks, the forecaster must first adjust the temperature curve to approximate the low level temperature at that time. In both cases, the forecaster will need to forecast changes in the vertical wind profile to determine the top of the mixing level. After the forecaster has made these changes on the Skew-T, you can complete the MCL as follows:

1. Draw a horizontal line at the level of the top of the mixed layer.

2. Bisect the dew point curve with a mixing ratio line by the equal area method.

3. Bisect the temperature curve with a dry adiabat by the equal area method.

4. MCL is the level at which the mean mixing ratio and the mean dry



Determination of the mixing condensation level.

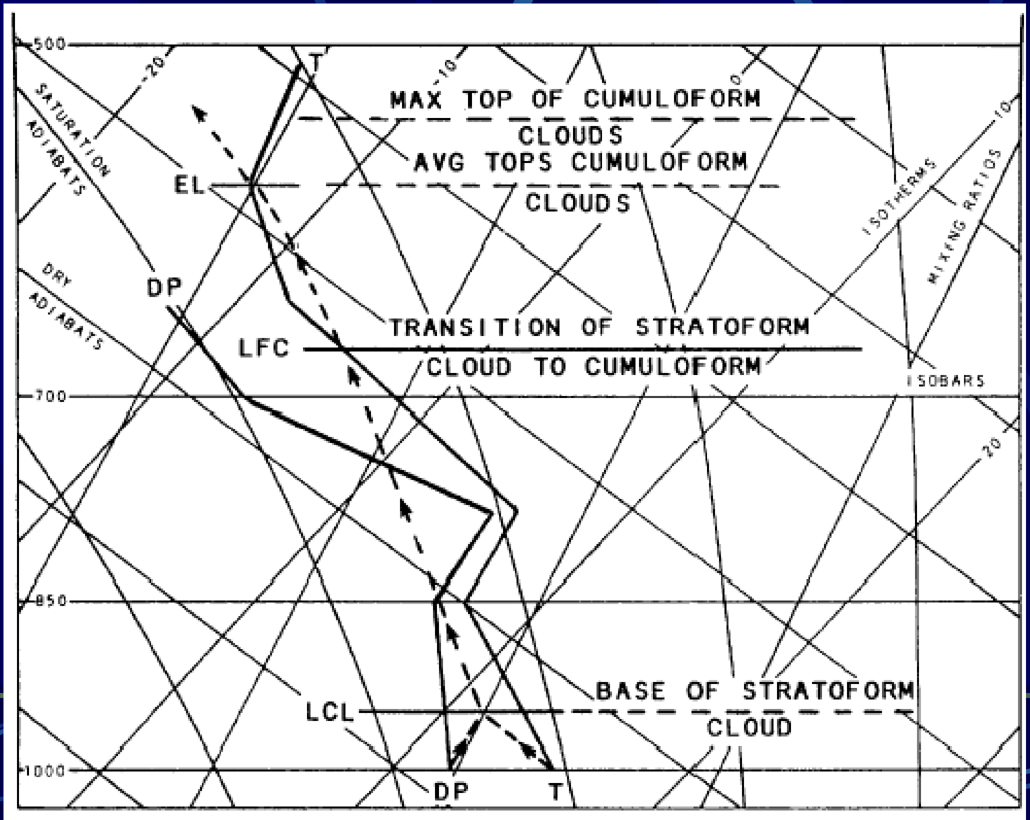
We have just looked at several methods used to determine where cloud bases will form. In reality, more than one factor can combine to start cloud formation. You may have a frontal surface moving through your area that will provide mechanical lift, but daily heating may occur to add convective lift to the process. You may have increasing winds to add mixing to the process. The forecaster must take these factors into consideration when

Level of Free Convection (LFC)

Level of Free Convection (LFC) is the level at which a parcel of saturated air becomes warmer than the surrounding air and rises freely. LFC in figure 6-2-10 is computed as follows:

1. Find LCL.

2. Draw a line upward from LCL parallel to the nearest saturation adiabat until your line intersects the plotted temperature curve. This is LFC .



Free convection in the atmosphere differs from forced convection in that free convection is brought about by one thing only—density differences within the atmosphere. When the required density difference does not exist, LFC will not exist. In such cases, the saturation adiabat drawn upward on the Skew T from LCL fails to intersect the plotted temperature curve.

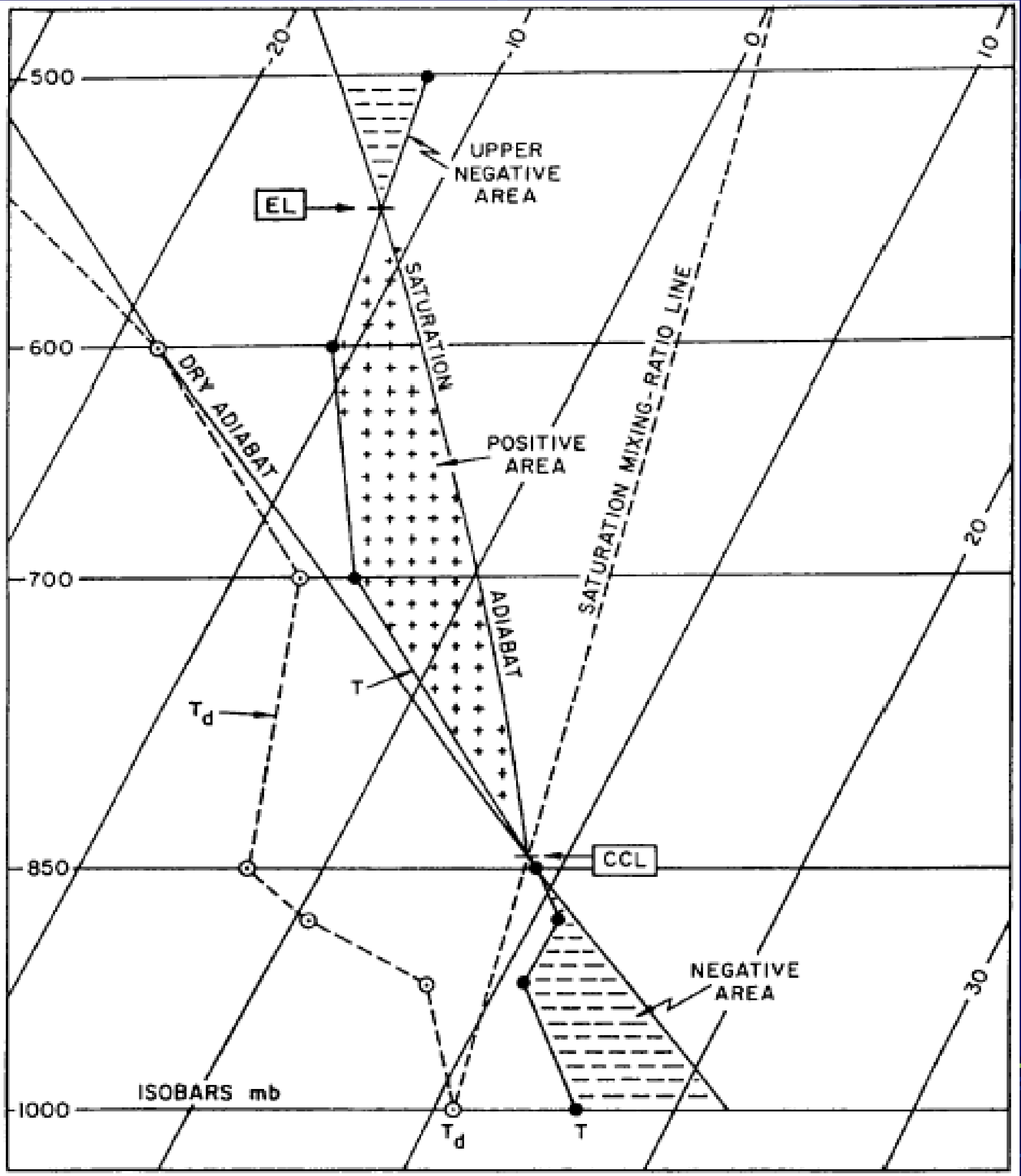
Once a cloud in the developing stage reaches LFC, the cloud will continue to develop until it enters a level where the surrounding air is cooler than the air in the cloud top. We will look at this in more detail in the following section on positive energy areas and negative energy areas.

Positive Energy Areas and Negative Energy Areas

Within the atmosphere, there are areas of positive energy and negative energy that control stability. These areas may be connectively or mechanically induced. The type and size of these energy areas often determine the type of weather that will occur over a region. When a parcel of air lies in a stable layer within the atmosphere, energy has to be supplied to it if the air parcel is to move up or down. Such a layer is classified as a negative energy area (NEA).

When an air parcel lies in an unstable layer within the atmosphere, energy need NOT be sup-plied to get the parcel to move. The parcel moves upward freely because it cools adiabatically and remains warmer than the surrounding air. Such a layer is known as a positive energy area (PEA).

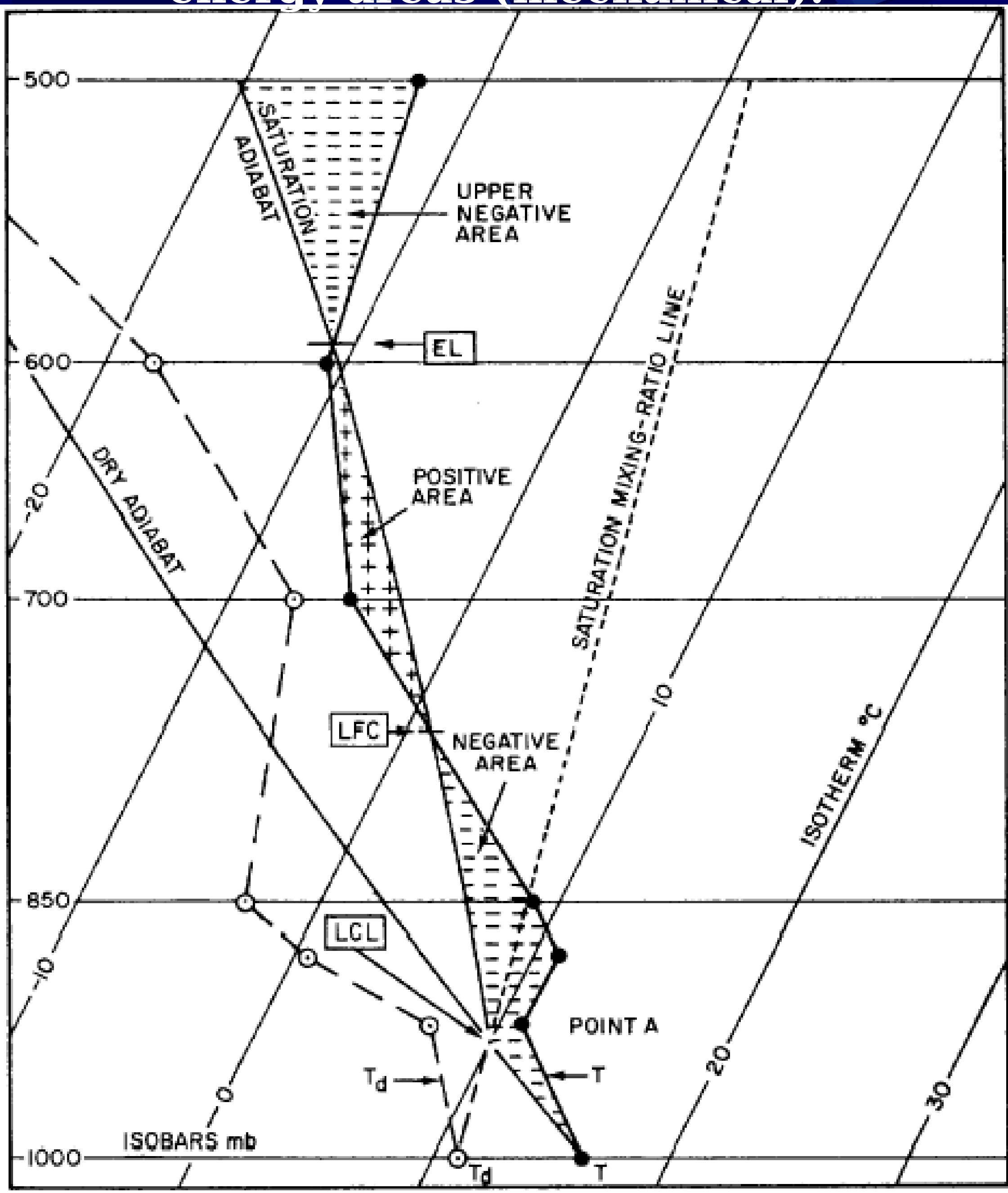
Positive energy areas and negative energy areas convective



Refer to figure to determine positive and negative energy areas pertaining to CONVECTIVE LIFTING. The procedure used in determining these areas is as follows:

1. Find CCL (moist-layer and/or parcel method).
2. From CCL, draw a line to the top of the chart paralleling the nearest saturation adiabat.
3. Draw a line from CCL to the surface paralleling the nearest dry adiabat.
4. Using a red pencil, shade in any area bounded by the temperature curve on the left and the drawn saturation adiabat on the right. These areas are the POSITIVE energy areas.
5. Using a blue pencil, shade in any area bounded by the temperature curve on the right and the drawn

Positive energy areas and negative energy areas (mechanical).



Refer to figure to determine positive energy areas and negative energy areas that pertain to MECHANICAL LIFTING. The procedure for determining these areas is as follows:

1. Determine LFC.
2. From LFC, extend the saturation adiabat to the top of the chart.
3. Using a red pencil, shade in any area above LFC that is bounded by the temperature curve on the left and the saturation adiabat on the right. These are PEAs.
4. Using a blue pencil, shade in any area above LFC that is bounded by the temperature curve on the right and the saturation adiabat on the left. These are NEAs.
5. Below LFC, shade in blue the area bounded on the right by the temperature curve, on the left by the dry adiabat, up

Equilibrium Level

Equilibrium Level (EL) is the height where the temperature of a freely rising parcel of air again becomes equal to the surrounding air. It is found where the saturation adiabat drawn upward from or LCL crosses the temperature curve from right to left. This is the level your energy area analysis changes from red to blue. You may find more than one EL on a certain sounding, just as you may find multiple PEAs and NEAs above LFC. Generally, you can equate EL to be the top of a stratiform cloud layer, but in the case of strong convective activity, over-shooting tops of cumulonimbus clouds may extend through EL by one-third the depth of PEA. For example, if PEA extends from at 4,000 feet all the way to an EL at 32,000 feet, you may calculate the maximum convective cloud tops to be as high as 41,300 feet.

So far we have looked at methods of computing the levels different types of clouds will form. However, analyzing clouds on the Skew T includes more than calculating where clouds will form. We must also be able to determine what layers already exist and what types of clouds are in the layers. This information will help the forecaster to predict the sky cover accurately. In the next section we will see how to determine where cloud layers should already exist and what types of clouds should be there.

Learning Objective:

Identify the criteria used in cloud layer analysis on the Skew

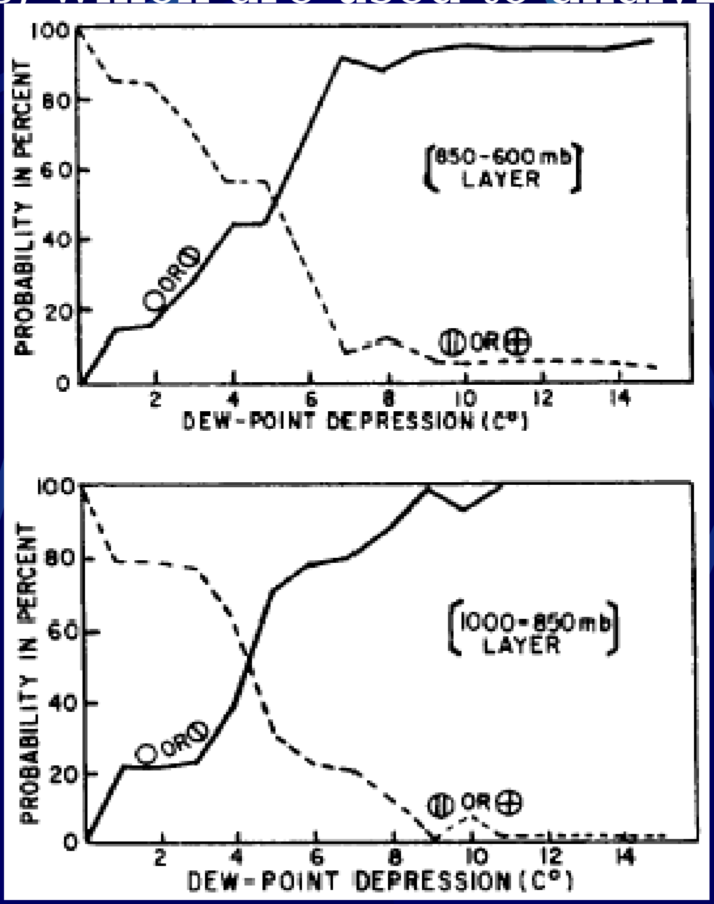
CLOUD LAYER CRITERIA

The Skew T gives you, the analyst, the best information to evaluate where cloud layers are and the type of cloud in each layer (short of sending an observer up in an aircraft). Analysis of moisture and winds can help you identify cloud layers missed by your observer at night or hidden by a low overcast. In this section we will see how to identify cloud layers by their moisture content and how you can identify the cloud type. We will also look at the association between cloud temperatures and precipitation, and some limitations in the identification of the taller cumuloform and cirriform clouds.

Cloud Layer Analysis

Studies have shown that water vapor becomes visible, as either minute water droplets or ice crystals, well below the saturation point. Other studies have correlated radiosonde observed temperatures and moisture measurements with aircraft observed cloud layers. While most aircraft reported cloud layers were supported by raob data, many thin or scattered cloud layers reported by aircraft often were not evident in the raobs. This was often interpreted as an accepted deficiency due to the lack of sensitivity of the older hygristors in the radiosondes. Nevertheless, the studies did find definite relationships between observed relative humidities and cloud layers.

Figure 6-2-13 shows the relationship between the dew point depression and cloud coverage that was determined by the study. Note that these results relate the dew point depression to the probability of occurrence of a scattered or overcast cloud layer. This study and other similar studies provided the basis for the following rules, which are used to analyze cloud layers on a Skew T.



Relationship of dew point depression to cloud cover.

- A cloud base maybe inferred to be located where the dew point depression decreases to 5°C or less when the air temperature is above freezing, or where the frost point depression is 5°C or less when the air temperature is below freezing. This is especially true if the dew point or frost point depression shows a sudden decrease near the same level.

- Dew point depressions in a cloud, on the average, are greater at cooler temperatures Use point depression of 4°C at –10°C, 5°C at –20°C, 6°C at

• If a layer of decrease in dew point (or frost point) depression is followed by a layer of sharper decreases, the base of the cloud layer should be identified with the base of the sharper decrease.

• The top of a cloud layer is usually indicated by an increase in dew point (frost point) depression. Once you identify a cloud base, extend the cloud upward until a significant increase in dew point or frost point depression is found. The gradual increase of dew point or frost point depression with height is usually not significant.

• Cloud cover may the dew point depression for above freezing temperatures, or from the frost point depression when below freezing temperatures ... wing thumb rules:

Depression, °C	Clouds – Weather
0 to 2	Overcast with possible precip-itation
2 to 4	Scattered to Broken
over 4	Widely Scattered to Clear

• The relative humidity is an even better guide for cloud coverage. Many forecasters use t

Relative humidity, percent	Dew/Frost point Depression, °C	Clouds (8ths)
≥90	0 to 1.2	8
85	1.3 to 1.8	7
	1.9 to 2.4	6
80	2.5 to 3.0	5
	3.1 to 3.5	4
75	3.6 to 4.0	3
70	4.1 to 4.5	2
	4.6 to 5.0	1
<65	>5.0	0

Finally, keep in mind that clouds tend to form in areas where some mechanism is providing lift. While we have previously discussed mechanical lift and thermal or convective lift, there is another important lifting mechanism in the atmosphere. This is vorticity. We discussed its effect on the atmosphere in *AG2*, Volume 1, Unit 8, Lesson 5. While vorticity would be difficult to analyze on the Skew T, a quick look at the plotted wind reports may give you a good idea of

Veering wind directions with height (direction changing clockwise with increasing height) usually indicate a positive vorticity pattern, while backing wind directions with height (directions changing counterclockwise with increasing height) usually indicate a negative vorticity pattern. As you probably remember, positive vorticity indicates lift and an up-ward transport of air, so you should expect cloud layers to increase in density. Negative vorticity, on the other hand, should gradually dissipate cloud layers.

Cloud Type Analysis

An evaluation of directional and speed shear in a moist layer also gives an indication of the type of cloud that maybe present. Relatively little shear indicates a stratiform cloud layer, while larger shear should be associated with a strato-, alto-, or cirro-cumuloform layer.

A thumb rule for finding the type of cloud in a layer uses the thickness of the moist layer as an indicator. If the layer is 1,000 to 4,000 feet thick, the cloud is stratiform; 5,000 to 9,000 feet thick, the cloud is cumuloform; and over 10,000 feet thick, it is towering-cumuloform. This thumb rule should not take precedence over an analytical procedure. Obviously it does not do justice to nimbostratus cloud layers.

Identification of the cloud genera is more straightforward. By definition, clouds with bases below 6,500 feet AGL are low-etage clouds: 6,500 feet to 18,500 feet AGL are mid-etage clouds, and above 18,500 feet AGL are high-etage clouds. Consult your *AG3* manual for a further breakdown of the low, mid, and high cloud types.

ASSOCIATION OF CLOUD TOP TEMPERATURES AND PRECIPITATION

The type and intensity of precipitation observed at the surface is related to the thickness of the cloud aloft and particularly to the temperatures in the upper part of the cloud. The processes that cause cloud particles to grow and precipitate out of clouds have received much attention during the past 30 years or so. However, our knowledge of the process is far from complete.

The results of one study relating cloud-top temperatures to precipitation type and intensity are applicable to the Skew T analysis when analyzing stratiform clouds. In 87 percent of the cases where drizzle was reported at the surface, the cloud-top temperatures were colder than –5°C. The frequency of rain or snow increased markedly when cloud-top temperatures fell below –12°C. During continuous rain or snow, cloud-top temperatures were below –12°C in 95 percent of the cases. Intermittent rain or snow fell from clouds with cloud-top temperatures colder than –12°C in 81 percent of the cases, and colder than –20°C in 63 percent of the cases. From this we can derive the rule that drizzle should be expected only when cloud-top temperatures are colder than –5°C and that continuous or intermittent rain or snow should be expected only when stratiform clouds, either layered or continuous, have cloud-top temperatures colder than –12°C. We cannot reverse this rule and say that we should expect precipitation if cloud-top temperatures are below –5°C. Whether precipitation occurs or reaches the

LIMITATIONS OF THE DIAGNOSIS OF TOWERING CUMULUS AND CUMULONIMBUS CLOUDS ON A SKEW T

The towering cumulus and cumulonimbus of summer- and tropical-air-mass situations are generally scat-tered. In many, if not most cases, they do not actually cover even half of the sky. Under such conditions, the probability that radiosondes released once or twice daily from fixed locations will pass up through a cloud of this type appears small. When a sonde does enter such a cloud, it is likely to pass out of the side rather than the top. Electrical charges in active thunderstorms have been seen to affect the sonde’s circuitry, yielding erratic readings.

Soundings that do pass through these clouds will often show unrepresentative values. The temperature in some parts of these clouds is often colder than that of the ambient, or surrounding, air. The lapse rate will not necessarily be saturation adiabatic, because of the effect of downdrafts, snow or hail melt, or entrainment and mixing. While humidity readings will be high, they also will not be representative of the surrounding air.

LIMITATIONS OF CIRRUS CLOUD IDENTIFICATION

True cirrus clouds form at temperatures near –40°C, or colder. Present rules for encoding Rawinsonde reports establish a cutoff point for reporting the dew point depression at this same temperature. This cutoff temperature was established because the hygristor elements in the older radiosondes were not reliable, and the data received from the sondes after that temperature was considered worthless. With the increasing use of the new humidity-measuring circuitry in radiosondes, this cutoff temperature may be changed to colder temperatures. Although not routinely reported, data from upper-air soundings indicates cirrus clouds layers are observable by at least an increase in the moisture (decrease in dew point depression) at temperatures colder than –40°C, even though the dew point was very low. If you are analyzing your own station's sounding, you should ignore the mandatory dew point cutoff for reporting and have the plotter enter the data on the Skew T. Analysis of this data using frost point calculations may yield some surprising heights for cirrus and may also end the typical standard observer entry for cirrus as either 20,000 or 25,000 feet.

Learning Objective:

Define the use of and describe the computation procedures for

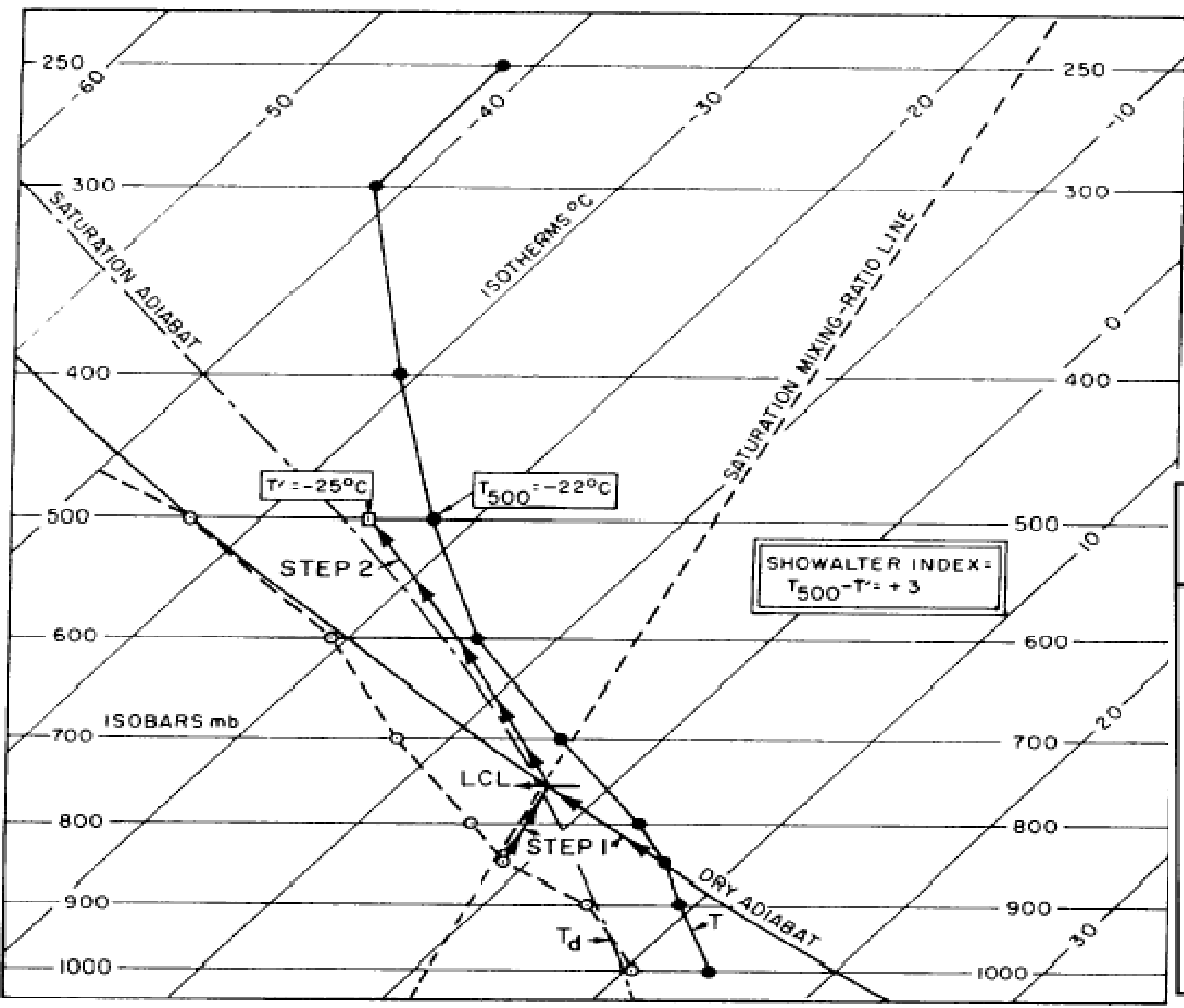
STABILITY INDICES

A stability index is a computed value used to forecast the probability of convective activity. This activity may range from rain showers, through the various intensities of thunder-storms, ending up with thunderstorms producing tornadoes. Many different stability indices are currently being used as forecast aids for severe weather. We will look at the indices used most frequently that you as the analyst must be able to compute from the Skew T. These are the Showalter Stability Index, the Lifted Index, the K-Value or K Index, and the Total Totals Index.

Showalter Stability Index (SSI)

The Showalter *Stability Index* (SSI) is the stability index most used by the National Weather Service, the USAF Air Weather Service, and Navy forecasters. It indicates the general stability of an air mass and should not be used when a frontal boundary or a strong inversion is present between the 850- and 500-millibar levels. SSI is computed using the layer between 850 millibars and 500 millibars, as follows:

1. Using the temperature and dew point at the 850-millibar level, determine LCL.
2. From that LCL, draw a line upward parallel to the nearest saturation adiabat until it intersects the 500-millibar level. Read the temperature (T') at this point.
3. Subtract T' from the actual 500-millibar temperature T_{500} This value. See figure 6-2-



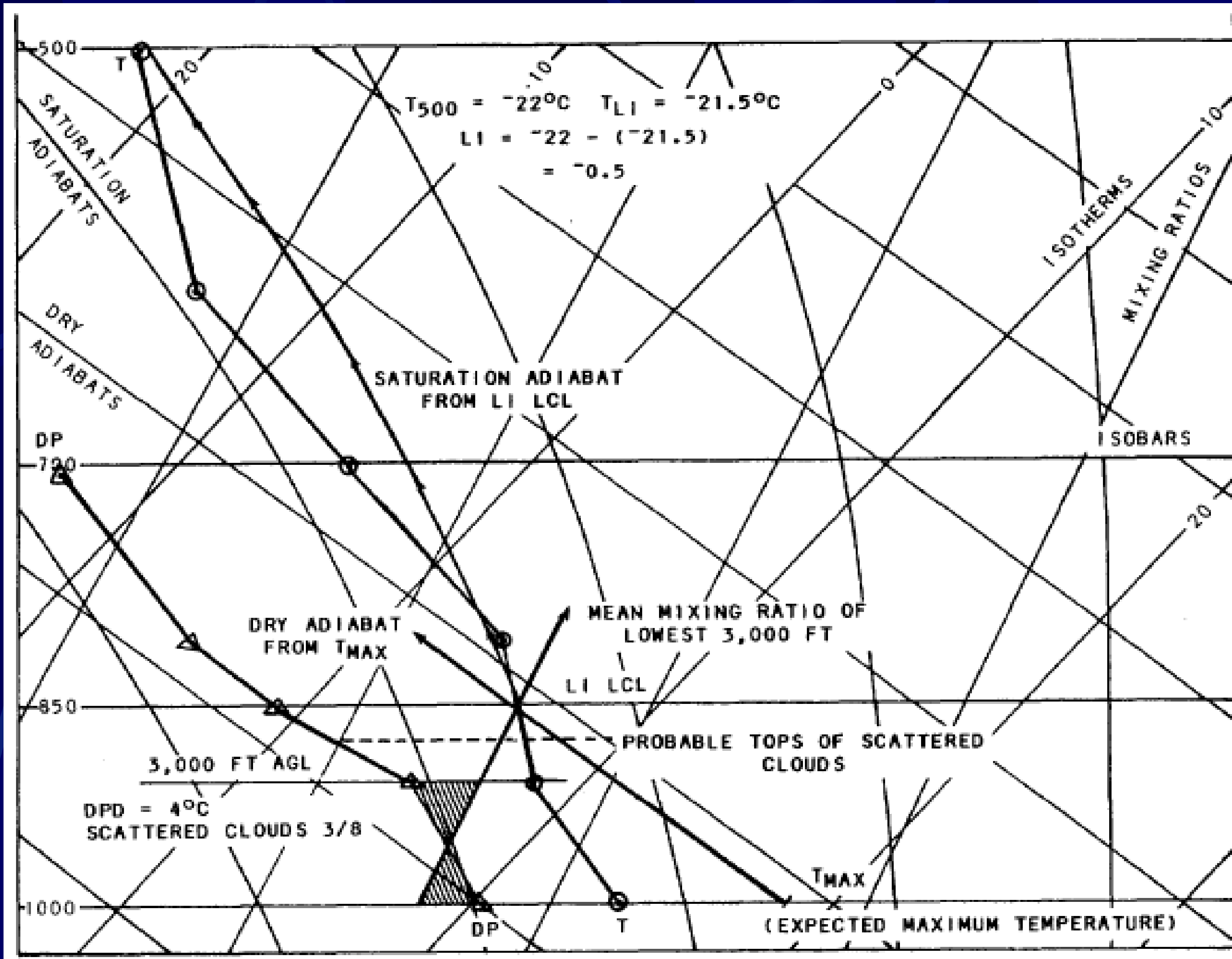
The probability of convective activity based m the SSI is as follows:

SSI VALUE	INDICATED WEATHER
>+3	RW/SW unlikely
+3 to +1	RW/SW probable and a slight chance of weak TSTM
+1 to −3	Increasing chance of TSTMS
−3 to −6	Probable Severe TSTMS
<−6	Possible TORNADOES

Lifted Index

Lifted Index (LI) is a modification of the Showalter Stability Index that is applicable for both air mass and frontal convective weather. The Lifted Index and the K-value (which we discuss in the following section) are routinely computed by the National Weather Service computers for all NWS U.S. Upper Reporting Stations and plotted on a chart for broadcast twice daily with the analysis package. The Lifted Index is computed from a Skew-T as follows:

1. Determine the mean mixing ratio in the lowest 3,000 feet of your sounding by the equal area method.
2. Draw the expected maximum temperature adiabat:
a. If the 850-millibar level is > 3,000 feet from the surface:
(1) if there are thick clouds on the current sounding, extend a saturation adiabat through the 850-millibar temperature so that it intersects your mean mixing ratio line; or
(2) if clouds are not expected to develop until afternoon, extend a dry adiabat through the 850-millibar temperature until it intersects the mean mixing ratio line.
b. If the 850-millibar level is within 3,000 feet of the surface, use the 3 ,000-foot temperature instead of the 850-millibar temperature to construct a dry or saturation adiabat.
3. The intersection of the mean mixing ratio and the adiabat is the Lifted Index LCL. Extend a saturation adiabat upwards from this LCL to the 500-millibar level. This 500-millibar tempera-ture is assumed to be the updraft



Computation of the Lifted Index

K Index

K Value or K Index is a measure of thunderstorm potential based on the temperature lapse rate, the moisture content of the lower atmosphere, and the vertical extent of the moist layer. It should be used to analyze the potential for air mass thunderstorm occurrence—not potential occurrences of frontal thunderstorms and not for the potential severity of a thunderstorm. The temperature difference between the 850- and 500-millibar levels is the parameter used to find the vertical lapse rate, and the 850-millibar dew point and the 700-millib … are used to evaluate the moisture content o … rtical extent of the moist layer. The K val …

$$K = (T_{850} - T_{500}) + T_{d_{850}} - Dpd_{700}$$

where K = K value

T_{850} = 850-millibar temperature,

T_{500} = 500-millibar temperature,

$T_{d_{850}}$ = 850-millibar dew point temperature, and

Dpd_{700} = 700-millibar dew point depression

Using the K Value as a predictor, you can determine the probability of thunderstorms with the following guideline:

K Value	Thunderstorm probability, percent
<15	0
15-20	0-20
21-25	20-40
26-30	40-60
31-35	60-80
36-40	80-90
>40	near 100

Total Totals Index

Total Totals Index is actually a compound index designed to more accurately predict the occurrence of severe weather. It is used for both air mass and frontal thunderstorm activity and should be calculated whenever SSI or LI indicate that thunderstorms may occur. To calculate the Total Totals index, you must first algebraically compute two values: the vertical total (VT) and the cross total (CT). Each of these values is used along with the Total Totals to assess the probability of severe thunderstorm occurrence. VT is a measure of vertical stability without regard for moisture. It is found by subtracting the 500-millibar temperature from the 850-millibar temperature.

CT is a measure of stability that includes moisture. It is found by subtracting the 500-millibar temperature from the 850-millibar dew point temperature.

The Total Totals (TT) index is simply the sum of VT and CT.

The forecaster will evaluate thunderstorm potential according to the general guidelines presented in table 6-2-1. While it is advisable to consider the VT and CT values, in common practice the TT index is the more reliable single predictor of severe activity in both warm- and cold-air situations. During 1964 and 1965, 92 percent of all reported tornadoes occurred with a TT of 50 or greater, with most family-type tornadic outbreaks occurring with a TT of 55 or greater. However, TT must be used with careful attention to either the CT value or the actual low-level moisture, since it is possible to have a large TT value with insufficient low-level moisture to support thunderstorms.

There are numerous other severe weather indices in use. Many of these are used at the National Severe Storms Forecast Center, by forecasters who specialize in severe weather forecasting. The indices presented here are those you should routinely evaluate when analyzing a Skew T diagram. If your calculated indices lead to a forecast of thunderstorm activity, your forecaster may ask you to calculate some additional parameters for wind gusts, convective turbulence, hail occurrence, and hail size. The procedures used to

Relationship of Severe Weather Intensities to the Magnitude of Cross-, Vertical-, and Total-Totals Indexes

FORECAST	CT	VT	TT
ISOLATED to FEW Orange	18-19	$\geq$26	44
SCATTERED Orange FEW Green	20-21	$\geq$26	46
SCATTERED Orange FEW Green ISOLATED Blue	22-23	$\geq$26	48
SCATTERED Green FEW Blue ISOLATED Red	24-25	$\geq$26	50
SCATTERED to NUMEROUS Green FEW to SCATTERED Blue FEW Red	26-29	$\geq$26	52
NUMEROUS Green SCATTERED Blue and Red	$\geq$30	$\geq$26	$\geq$56

Red = Severe Thunderstorms w/tornadoes a/o waterspouts
Blue = Severe Thunderstorms (max gusts $\geq$50 kts, a/o hail >1")
Green = Moderate Thunderstorms (max gusts $\geq$35 kts but <50 kts, a/o hail $\geq$1/2" but $\leq$1")
Orange = Thunderstorms (max gusts <35 kts a/o hail <1/2")

REGIONAL MODIFICATIONS:

WEST OF THE ROCKIES – 700 and 500 millibar dew point depressions should be less than 6 °C to insure sufficient low level moisture or 500 millibar temperature should be ≥ -17 °C and 700 millibar temperature should be ≥ 0°C. If this is satisfied, then consider: (a) VT <28 = No thunderstorms. (b) VT $\geq$28 but $\leq$32 = Few thunderstorms. (c) VT $\geq$32 = Scattered thunderstorms. Usually these will be Orange variety. Green or blue require large amounts of moisture at 850 and 700 millibars.

PACIFIC COASTAL MOUNTAINS, WINDWARD SLOPES – Vertical totals are most important predictor, especially when associated with PVA and cyclonic flow aloft. Over OR, WA and northern CA VT $\geq$30 will usually produce Cumulonimbus with few Tstms and hail pellets.

EAST OF ROCKIES – Use above values if sufficient low level moisture is present.

GULF COAST AND GULF STREAM – Predict thunderstorms if CT $\geq$16 and VT $\geq$23.

GREAT LAKES – Vertical totals are the more important predictor. Any value $\geq$30 should produce thunderstorms, except if the lakes are frozen over or mostly frozen over.

Learning Objective:
Describe the computation procedure for convective activity

COMPUTATION OF CONVECTIVE ACTIVITY FORECAST GUIDES

As the analyst of the Skew T diagram, you will calculate critical values upon which the forecaster will base his thunderstorm fore-cast. You have already determined that thunder-storms may occur and have used the indices to find a probability of occurrence and a prediction of the general strength of the expected thunder-storms. Now the forecaster must make a determination of the maximum gusts expected and what size hail is expected, if any. With this information, the forecaster may issue a thunderstorm warning or recommend that the proper thunderstorm condition be set. The following techniques will allow you to calculate wind gust speed and direction, to determine if hail is expected, hail size, and the strength of turbulence expected in the convective activity.

Calculations for Convective Wind Gusts

There are two methods for calculating convective gusts. These are the T_1 and T_2 methods. The T_1 method is used to predict average maximum gusts and the maximum wind gust in air mass thunderstorms. The T_2 method should be used to compute the maximum wind gust in frontal thunderstorms or in a prefrontal squall line, when numerous air mass thunderstorms are expected, or when an air mass meso-scale convective thunderstorm complex threatens your station. In brief, use the T_1 method for thunderstorm gusts at your station when thunderstorms are expected in the vicinity, and use the T_2 method if a thunderstorm is expected to pass directly over your station with heavy rain. The maximum downrush wind or microburst will occur as the transition between the mature stage and the dissipating stage of a strong thunderstorm coincident with the beginning of the heaviest precipitation.

The most severe weather appears to occur in areas where the height of the Wet-Bulb-Zero (WBZ) is less than 10,500 feet. Wet-Bulb-Zero heights between 7,000 and 9,000 feet above the ground are most closely associated with destructive surface winds caused by microbursts from thunderstorms. Microbursts are extremely rare with a WBZ height lower than 5,000 feet or higher than 10,500 feet

T_1 Method For Air Mass Convective Gusts

The T_1 method uses the calculated difference between the temperature of a parcel of moist surface air raised moist adiabatically to 600 millibars and the 600-millibar temperature as a guide to determine the surface wind gusts. The computation procedure is as follows:

1. Have the forecaster determine what time the thunderstorms are expected to occur, and the maximum temperature expected during that time period.
2. If an inversion is present within 200 millibars of the surface and the inversion will not be removed by diurnal changes, from the warmest point in the inversion ascend moist adiabatically to 600 millibars, and record the temperature. If no strong inversion is present, ascend moist adiabatically from the predicted maximum temperature to 600 millibars, and record this temperature.
3. Subtract the actual 600-millibar tempera-ture from the temperature you $V' = 13 \sqrt{T_1}$ nd and recorded. The difference between these two temperatures is the T_1 temperature.
4. Enter table 6-2-2 with T_1 to find the average maximum gust speed (V') The table is based on the formula with some empirical adjustments.
5. Calculate the mean wind speed in the surface-to-5,000-foot layer.

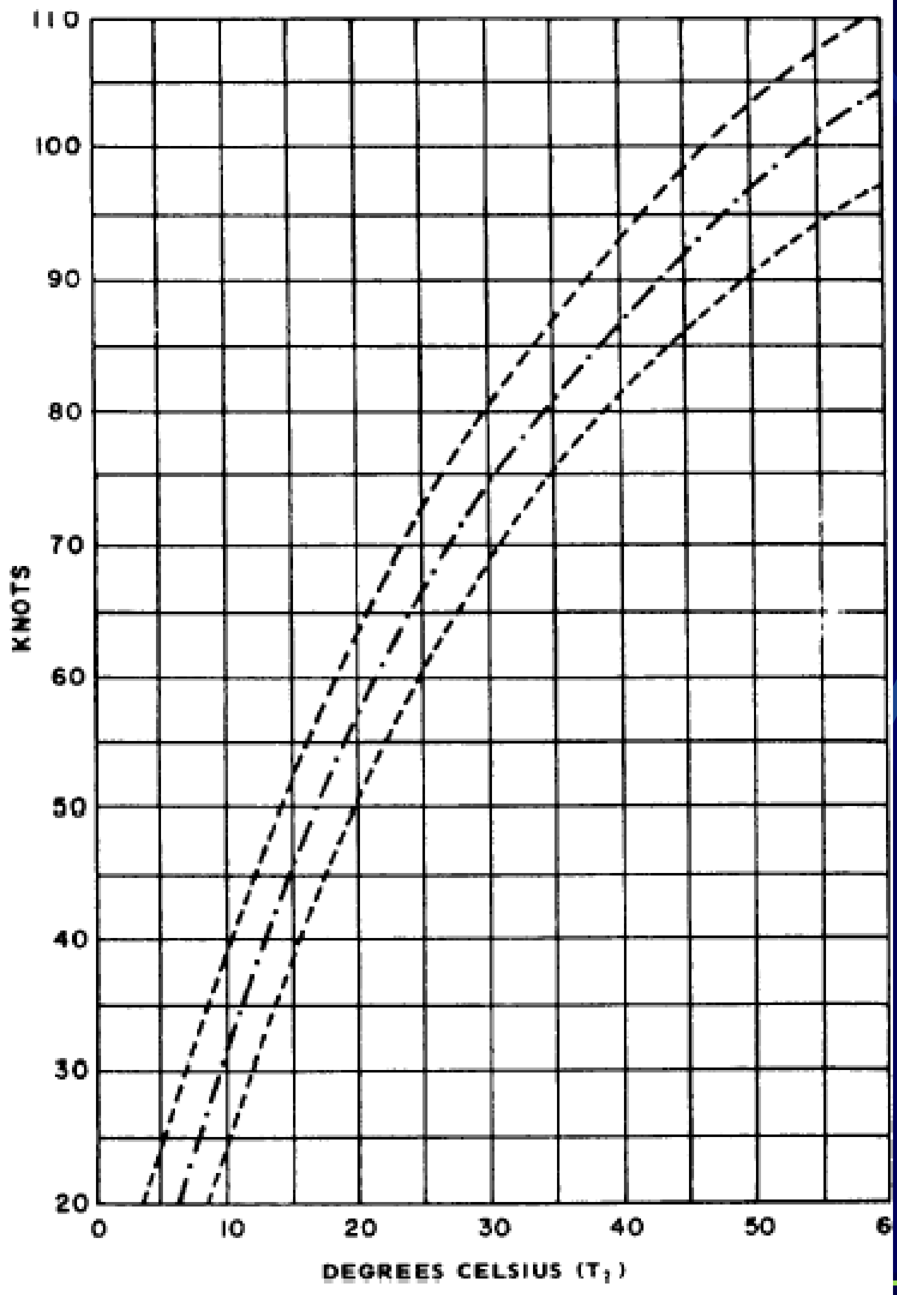
T_1 Values in °C	Maximum Gust Speed (V')	T_1 Values in °C	Maximum Gust Speed (V')
3	17	15	49
4	20	16	51
5	23	17	53
6	26	18	55
7	29	19	57
8	32	20	58
9	35	21	60
10	37	22	61
11	39	23	63
12	41	24	64
13	45	25	65
14	47		

Average Maximum Convective Wind Gusts for the Method

T_2 Method for Computing Maximum Convective Gusts From Frontal or Air Mass Thunderstorms

The T_2 method uses the difference between the maximum surface temperature at the time thunderstorms are expected as a predictor of the WBZ potential temperature at the time probable maximum gust speed to expect from a thunderstorm outbreak. The gust speed is found by the following steps:

1. Have the forecaster determine what time thunderstorm activity will commence and what the maximum temperature will be at that time.
2. Locate the WBZ.
3. Descend moist adiabatically from WBZ to the surface and record this temperature.
4. Subtract this temperature from the predicted maximum temperature at the onset of the thunderstorm activity to find T_2
5. Enter figure 6-2-16 to find the probable range of the expected maximum gust speed. This figure does not yield average gust speeds or minimum gust speeds. If T_2 is 20°C, for example, you would tell the forecaster that the expected maximum gust will be in the 51- to 68-knot range, with a most probable value of 57 knots. You may wish



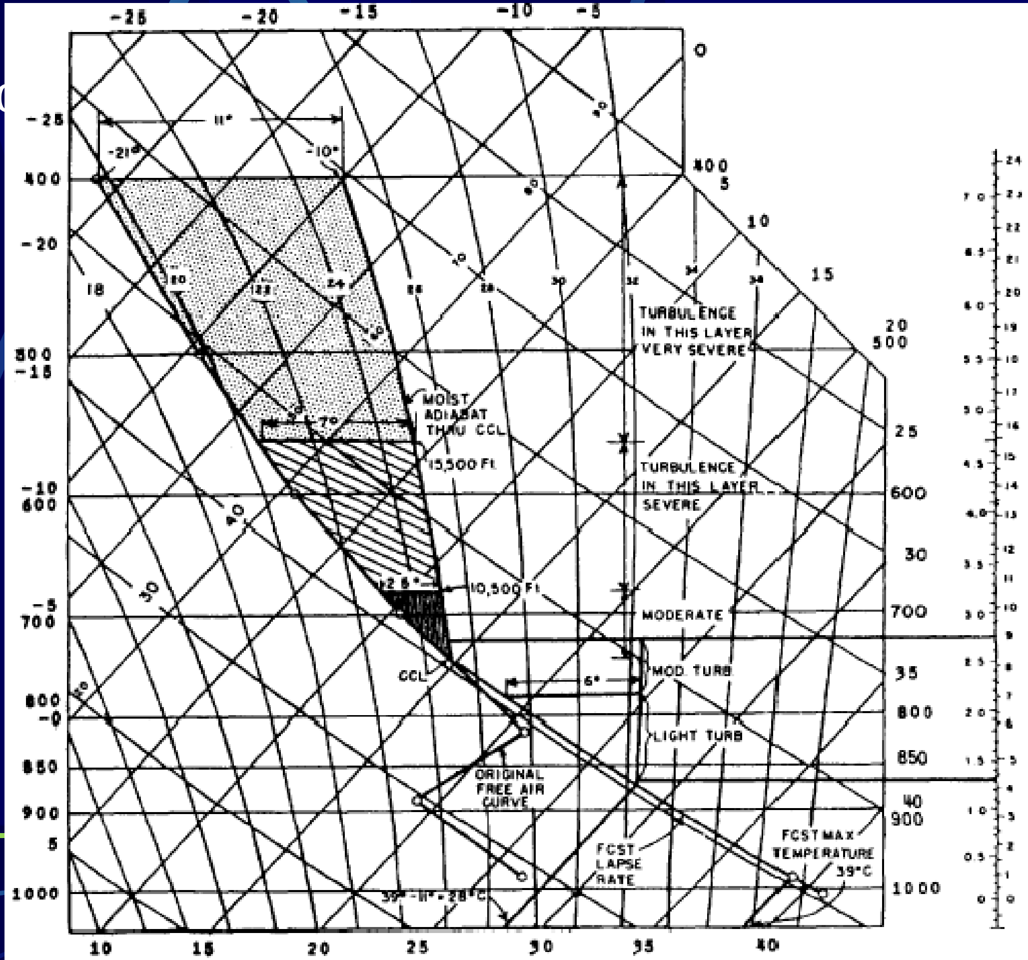
T_2 method of maximum convective wind speed gust diagram

Computation of Gust Direction

Once you have calculated the gust speed, use the plotted wind speeds and height scale to find the mean wind direction in the 10,000 foot to 14,000 foot AGL layer. Use this direction as the direction for the maximum gust. Remember, a thunderstorm downrush, with its associated gusts, spreads out in all directions under the thunderstorm base. Your maximum gust direction should generally be in the same direction the storm is moving. When calculating a maximum gust direction in a frontal thunderstorm, you should consider the 10,000- to 14,000-foot wind as representative even if the thunderstorm is occur-ring on the cool side of the surface position of the front. The slope of both warm and cold fronts allows either a warm sector sounding or a pre-warm frontal sounding to be representative for the 10,000- to 14,000-foot winds.

Calculating Convective Turbulence

The following is the modified Eastern Airlines method of calculating expected turbulence within a convective cloud, using a plotted Skew T, Log P Diagram. The resulting turbulence criteria are based on a medium-size, twin-engine, fixed-wing aircraft (DC-3/C-117/C-47, length 65 feet, wing span 95 feet) and must be adjusted subjectively for other aircraft. You may wish
you read through the computatio



1. Divide the plotted atmosphere into two layers at the 9,000-foot MSL height.
2. Plot the forecast maximum temperature (FMT) on the surface level.
3. From the convective condensation level (CCL), descend dry adiabatically to the surface to locate the convective temperature (CT), and have the forecaster adjust CT according to local-objective techniques and expected insolation.
4. Subtract 11°C from FMT to give a new temperature, which we will designate T_3
5. Find the intersection of the T_3 isotherm and the dry adiabat projected upward from FMT.
• If the intersection occurs above 9,000 feet, no turbulence is expected below 9,000 feet. Go to step 7.
• If the intersection occurs belov … th step 6.
6. Draw a moist adiabat from the … the 9,000-foot level. The temperature diffe … adiabat and the ambient temperature de … he turbulence that should be expec … uds. Use the following guideline:

SURFACE TO 9,000 FOOT MSL LAYER	
TEMPERATURE DIFFERENCE, °C	TURBULENCE
0 to 5.9	LIGHT
6.0 to 10.9	MODERATE
≥11	SEVERE

7. For the layer above 9,000 feet, project a moist adiabat upward from the CCL to the 400-millibar level. The maximum temperature difference between the moist adiabat and the free air temperature is the most turbulent [illegible] classified as follows:

9,000 FOOT MSL TO ABOVE THE 400 MB LAYER	
TEMPERATURE DIFFERENCE, °C	TURBULENCE
0 to 2.4	MODERATE
2.5 to 6.9	SEVERE
≥ 7	EXTREME

8. If two criteria overlap near the 9,000-foot level, use the greater turbulence.
9. If the CCL is above 9,000 feet, evaluate turbulence from CCL upwards only.

Computing Hail Occurrence

Just as the WBZ height is an important and reliable indicator of thunderstorm gusts, it is also a reliable preliminary indicator of hail occurrence. Research has shown that 84 percent of all cases of hail occur with the WBZ between 5,000 and 10,500 feet AGL. Furthermore, nearly all analyzed cases of hail larger than 1/2 inch occurred where the WBZ was near 8,000 feet AGL. Although many strong thunderstorms were studied where the WBZ was higher or lower than these values, most did not produce hail or strong gusts at the surface even though various indicators showed that the potential was present and that hail was almost certainly produced aloft. In the 16 percent of the cases where hail did occur at the surface with WBZ heights outside the 5,000- to 10,500-foot range, the hail fell only for a short period and was small. These cases occurred mostly in the states along the Gulf Coast.

Hail, like the maximum wind gusts, usually occurs in a narrow shaft seldom longer than a mile or two and less than a mile wide

HAIL ALOFT

Since hail is normally associated with thunderstorms, the season for hail occurrence is the season for thunderstorm occurrence. When a thunderstorm is large and well developed, you should assume that it contains hail aloft. Below 10,000 feet, aircraft may encounter hail in the rain shaft under the storm, in the clear air within 2 miles of the storm cloud, and in the thunderstorm cloud itself, with equal probability. From 10,000 to 20,000 feet, 40 percent of aircraft hail encounters occur in the clear air under the overhanging tilted cumulonimbus column or the anvil, while 60 percent occur within the cumulonimbus column. Above 20,000 feet, 80 percent of hail encounters are within the cloud, while 20 percent are under the anvil. No computations are required to determine if hail is present aloft. Assume that it is.

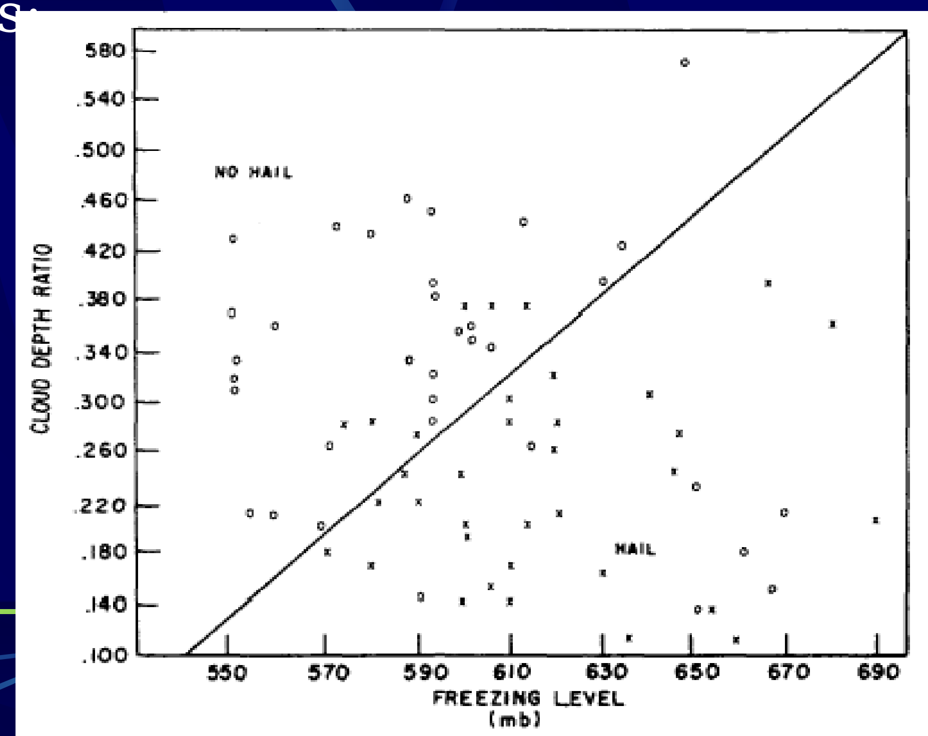
HAIL AT THE SURFACE

Will the hail reach the surface? If the WBZ height is favorable (5,000 to 11,000 feet for most areas), proceed with the following objective computation for a simple "yes" or "no" determination. If you are stationed along the Gulf Coast or in areas climatically similar to the Gulf Coast, you should use the procedure even though the WBZ exceeds 11,000 feet.

1. Find CCL_{ML+} EL, and the freezing level (FzL), in millibars.
2. Calculate the ratio of the depth, in millibars, of the freezing level to *CCL*, compared to the *EL* to *CCL* depth. This is the cloud depth calculated as follows:

$$\text{ratio} = \frac{|CCL - FzL|}{CCL - EL}$$

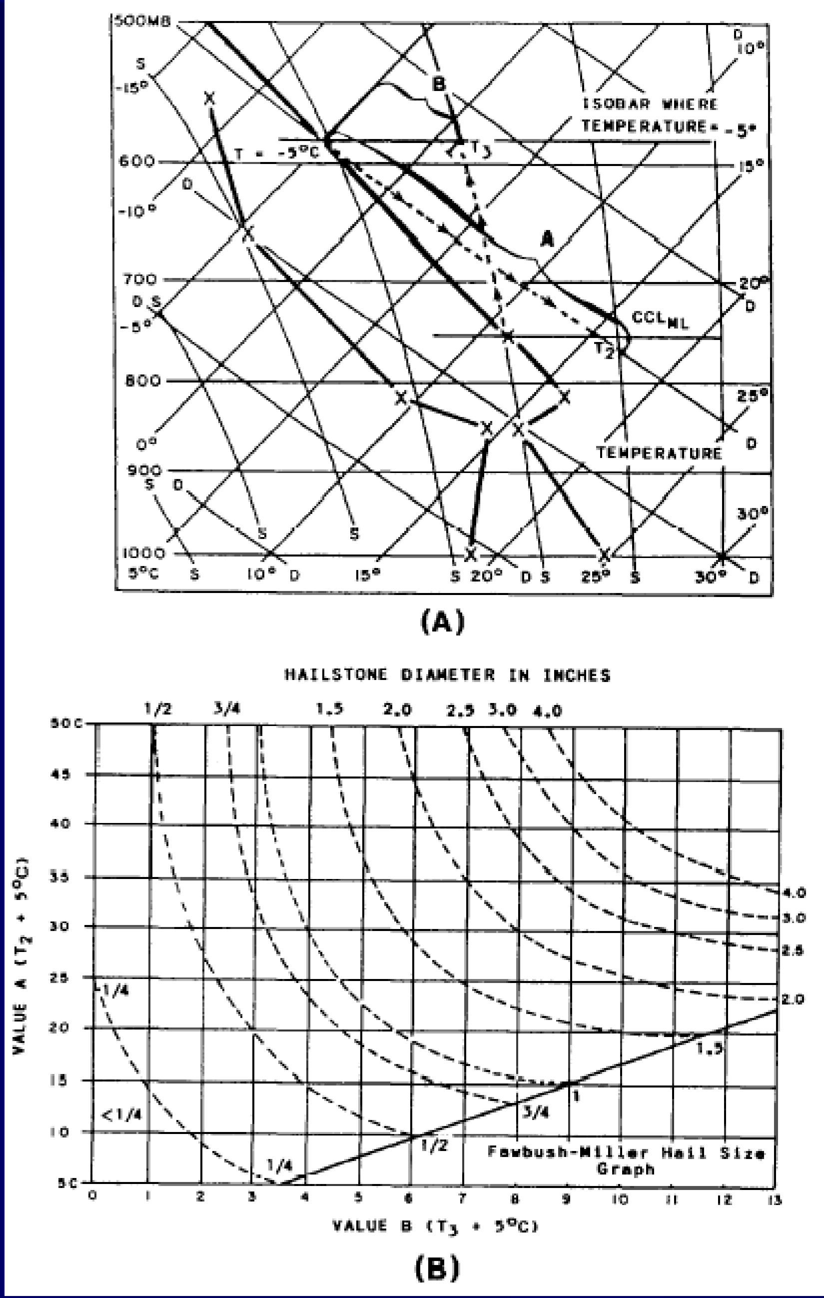
3. Enter figure 6-2-18 with the cloud depth ratio and the freezing level, in millibars, for a "yes" or "no" prediction of hail reaching the surface.



Computation of Hail Size

This method of computing hail size is based on the estimates of updraft and downdraft velocities in thunderstorms and the resulting probabilities of hail produced in a thunderstorm reaching the surface. This technique is called the Fawbush-Miller Hail Forecast method. The procedure to calculate hail size is as follows:

1. From the temperature curve at –5°C, extend a dry adiabat downward until it intersects the pressure level of CCL_{ML+} and read the temperature T_2 at this intersection. We will call this temperature in our example, figure 6-2-19, view A.
2. Calculate the difference between this temperature (T_2) and –5°C. Call this value *A*. The difference is $T_2 - (-5\,°C)$, or simply $T_2 + 5\,°C$.
3. From the CCL_{ML+} intersection with the temperature curve, draw a saturation adiabat up-ward to intersect the pressure level where the air temperature is –5°C, and read the temperature at this intersection. We will call this temperature T_3 in our example.
4. Calculate the difference between this temperature T_3 and –5°C. Call this value *B*. This difference is $T_2 - (-5\,°C)$, or simply $T_2 + 5\,°C$.
5. Enter figure 6-2-19, view B, with values *A* and *B* to find the hail size on the Fawbush-Miller Hail Graph.



Surface-hail-size calculation: (A) Calculation example, (B) hail size graph.

Learning Objective:
Describe the computation procedure for contrail formation

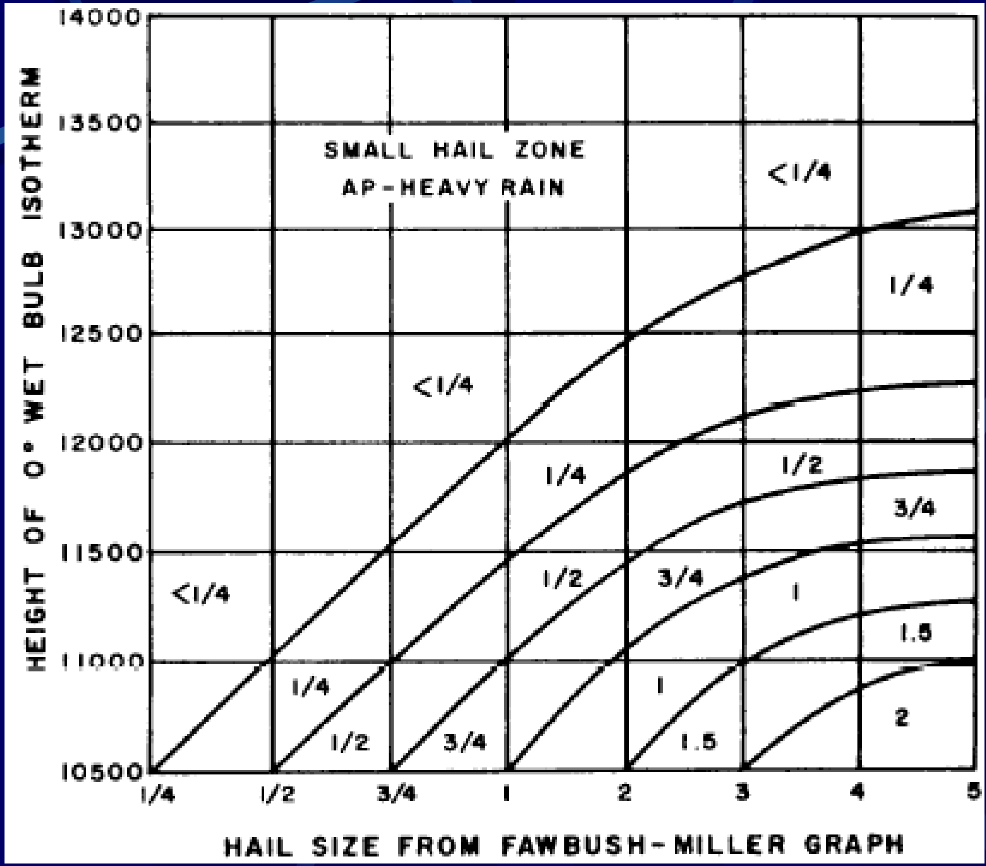
CONTRAIL COMPUTATION ON THE SKEW T DIAGRAM

Condensation trails, abbreviated *contrails,* are elongated, tubular-shaped clouds composed of water droplets or ice crystals which form behind an aircraft when the wake becomes supersaturated with respect to water. There are two types of contrails: aerodynamic contrails and engine exhaust contrails.

Aerodynamic contrails form by the momentary reduction of air pressure in the airfoil vortex. If you have ever seen the Navy Blue Angles or the Air Force Thunderbirds during a low-level demonstration, then you have probably noticed these contrails trailing the wing tips, especially during high-speed turns. These contrails appear as the vortex creates a partial vacuum, lowering the air pressure sufficiently to bring it to saturation. They dissipate rapidly as the pressure in the vortex returns to normal behind the aircraft. We will not be concerned with this type of contrail.

The second type of contrail is the engine exhaust contrail, formed by exhaust water vapor, a by-product of the combustion process, bringing the air to saturation. These are the conspicuous contrails

Why are we concerned with contrail analysis and forecasting? Contrails can make an otherwise inconspicuous high flying aircraft very noticeable.



In a warfare situation or while conducting covert high-altitude photo-reconnaissance, a key to the success of the mission may be the element of surprise. Our aircraft may wish to avoid flight altitudes conducive to contrail formation to decrease the probability of their detection. Stealth technology aircraft will especially wish to avoid producing contrails. Shipboard, the CIC officer and the OOD

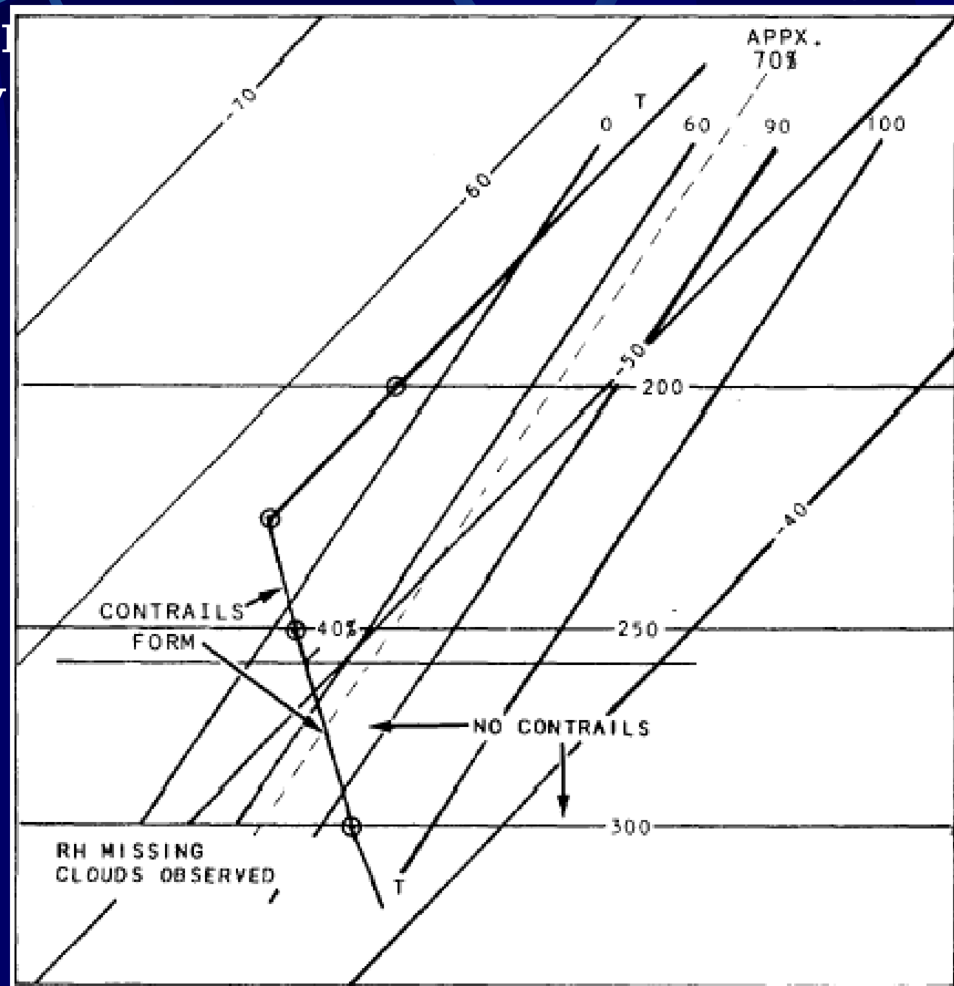
We have already identified the contrail scales and their values on the Skew T diagram earlier in this lesson. Given a specific level, you can use these scales, the temperature, and the humidity to determine if contrails will form.

When the free-air temperature is to the right of the 100 percent line, contrails will not form, regardless of the humidity.

When the free-air temperature is to the left of the 0 percent line, contrails will form, regardless of the humidity.

When the temperature is between the 0 percent and 100 percent lines, contrail formation depends on the humidity. The relative humidity must be equal to or greater than the value indicated by the line for contrail formation to occur. If the temperature at 300 millibars is –45°C, for instance, the temperature is just to the right of the 60 percent line. I would call it about 67 percent. Contrails will form only if the relative humidity at that level (evaluated with respect to ice) equaled or exceeded 67 percent. Right about now you

When the humidity data is unknown, empirical data indicates good results are achieved if 40 percent humidity is assumed where there are no clouds reported at the level, and 70 percent humidity is assumed when clouds are reported at a level. See figure 6-2-21 for an example of a contr s are present but relative humidity



Learning Objective:

Describe the computation procedures for icing level analysis

ICING COMPUTATIONS ON THE SKEW T

You learned in the previous lesson how to evaluate icing type, and you were given some subjective rules for icing intensity. We must use more than "guesstimation" when flying safety is at stake. In this section we will discuss two icing analysis techniques for use on the Skew T. The Minus 8D technique is a method which gives a simple Yes or No evaluation of conditions favor-able for icing. The second technique will yield a qualitative analysis of icing intensity. Although there are a lot of calculations that must be done in this technique, it is far better to use this technique than estimation when attempting to analyze and forecast hazardous conditions such as icing. One of my most memorable days on the Flight Forecast Counter occurred one winter day, when analysis of data, including several Skew T’s, indicated severe clear and mixed icing conditions north of NAS Norfolk, extending well north of Washington, D.C. I used the "Flight Not Recommended" stamp on three dash-one briefs to end the arguments by pilots who just "had to" fly to the D.C. area. Although two of the three pilots became very irate, I felt great about my decision after hearing of a tragic accident involving a major passenger jet that crashed into the Potomac River because of icing. They could have ended their flights the same way. If I had used

Minus 8D Icing Analysis

Physical observations of clouds often fail to give any indication of the composition of the clouds—whether they are water, water and ice mixed, or entirely made up of ice crystals. In any convective cloud, it is reasonable to assume that they are made of a mixture of ice and water at temperatures below freezing. In the stratus cloud, however, it is not safe to assume this. Clouds com-posed entirely of ice present little icing hazard. Clouds below freezing composed of mixed water and ice present a great icing hazard. Therefore, it is helpful if you know the cloud composition before you brief a flight through the cloud.

In a mixed ice and supercooled water cloud, evaluation of the dew point and the frost point would show that the cloud may be near or at saturation with respect to water but that the cloud would be supersaturated with respect to ice. We can assume that a cloud that is saturated with respect to ice would be subsaturated with respect to water and that it would consist entirely of ice crystals. Now, we could evaluate the humidity at all levels based on the dew point and frost point to see where icing will occur; or, we can use the *Minus 8D Icing Analysis* to show at a glance those areas that are supersaturated with respect to ice (are composed of supercooled

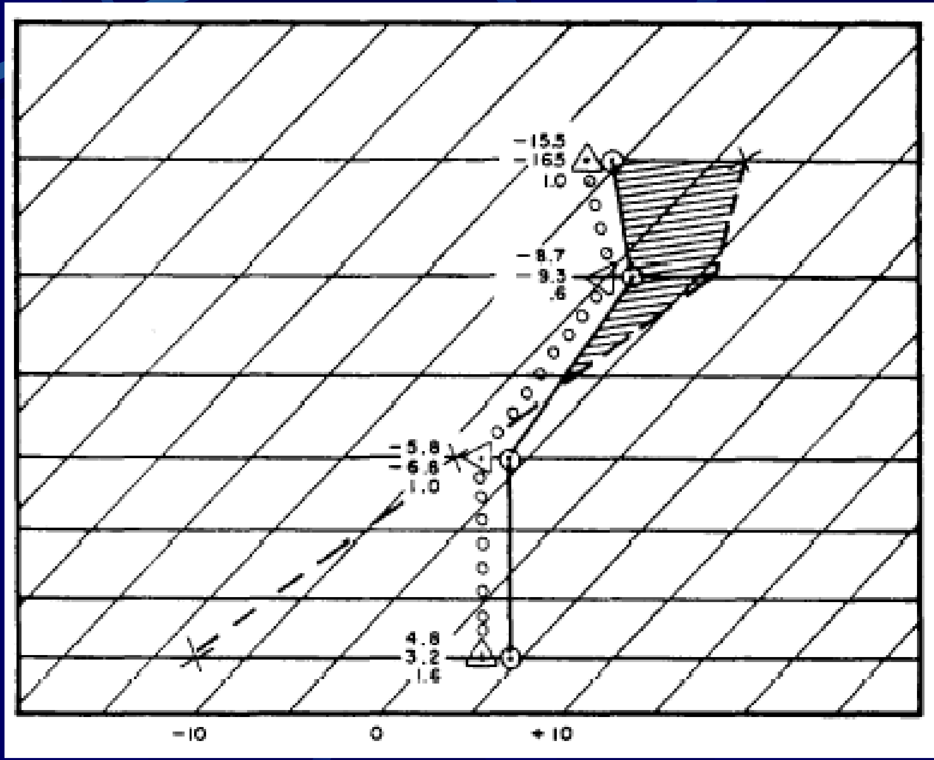
1. Task the Skew T plotter to enter the reported dew point depression (as the chart is being plotted) just to the left of the dew point temperature plot for all levels where the air temperature is below freezing. An alternative is to calculate the difference between the plotted dew point temperature and the air temperature and enter this value (always a positive number) just to the left of the plotted dew point temperature. In this case, the value is called *D* even though it is the dew point depression, It should be found to the nearest tenth.

2. Multiply *D* by –8 and plot this value (°C) the appropriate temperature on the same pressure level. For instance, if your dew point depression, or *D,* is 1.1, you would multiply this by –8 to find a product of –8.8°C. This would be plotted on the appropriate isotherm. The color used for the plot is established locally. I have seen green used most often.

3. Connect all of your plotted –8D values

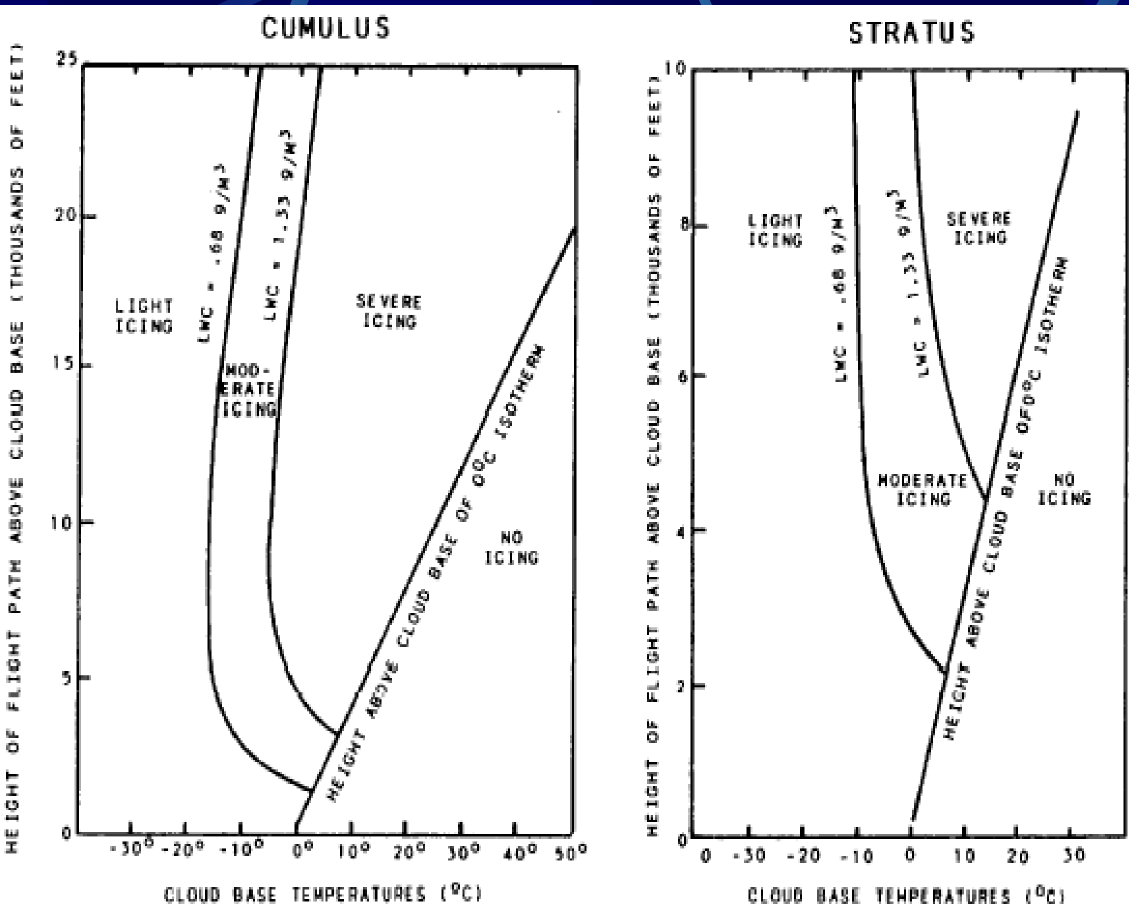
4. Conditions are favorable for aircraft icing where the line falls on the right side of the temperature curve. Evaluate flight levels for the base of each icing layer and the thickness of each layer, in

See figure 6-2-22 for an example of a –8D analysis of an icing layer. This technique does not indicate the intensity or type of icing in a layer, only that icing conditions are favorable or unfavorable.



Maximum Icing Intensity Analysis

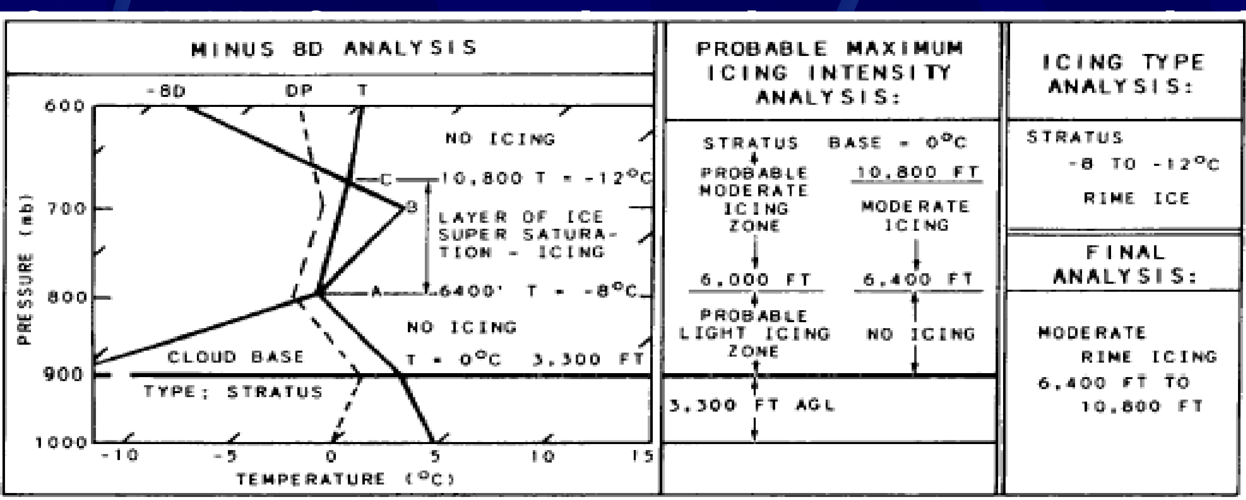
The two graphs in figure 6-2-23 may be used valuate the maximum probable icing in a cloud after you have determined that icing conditions are favorable. $LWC = (W_0 - W_1)\frac{P_1}{2.87T_1}$ were constructed from the formula:



where LWC = liquid water content, in grams per cubic meter;
W_0 = saturation mixing ratio at cloud base, in grams per kilogram;
W_1 = saturation mixing ratio at an evaluated level in the cloud;
P_1 = atmospheric pressure at the evaluated level within the cloud; and
T_1 = temperature (kelvin) at the evaluated flight level.

The graphs, which compensate for adjusted lapse rates, were constructed for values of LWC tabulated against cloud heights. The cumulus graph has been constructed for clouds having bases near 950 millibars; and the stratus graph, for clouds with bases near 850 millibars. Deviations for these types of clouds with bases at different levels are very slight and may be ignored. The LWC values indicated on the graph are the critical values necessary to produce the icing intensities indicated by the areas they separate. The location of the LWC lines is based on studies of moisture distribution in clouds at different levels and the typical lapse rates within those types of clouds.

When you have determined that icing exists by the Minus 8D method, locate the base of the cloud. Read the temperature at the cloud base. From the cloud base temperature, go straight up the graph to determine the maximum probable icing in the cloud for the height above the cloud base. For instance, with a stratiform cloud base temperature of 10°C, you would evaluate no icing up to 3,000 feet or so above the cloud base, moderate icing from 3,000 feet to 5,000 feet, and severe icing from 5,000 feet upwards. Adding these values to the actual height of the cloud base will give you the heights of the probable maximum icing intensity. Figure 6-2-24 shows the maximum probable intensity of icing analysis for the example we used in the Minus 8D method. In this example, let's assume a nimbostratus cloud base at 900 millibars (3,300 feet) and a cloud base temperature of 0°C. Using the stratus graph, we would evaluate light icing to 2,700 feet above the cloud base, with moderate icing above 2,700 feet. Since the cloud base is at 3,300 feet, the graph would tell us that the maximum probable icing in this case is light icing from 3,300 feet to 6,000 feet (3,300 + 2,700), with moderate icing



shows icing only from

vould combine the two

feet to 10,800 feet. Use

o this icing.

Example combining Minus 8D analysis, maximum probable icing analysis, and icing type analysis.

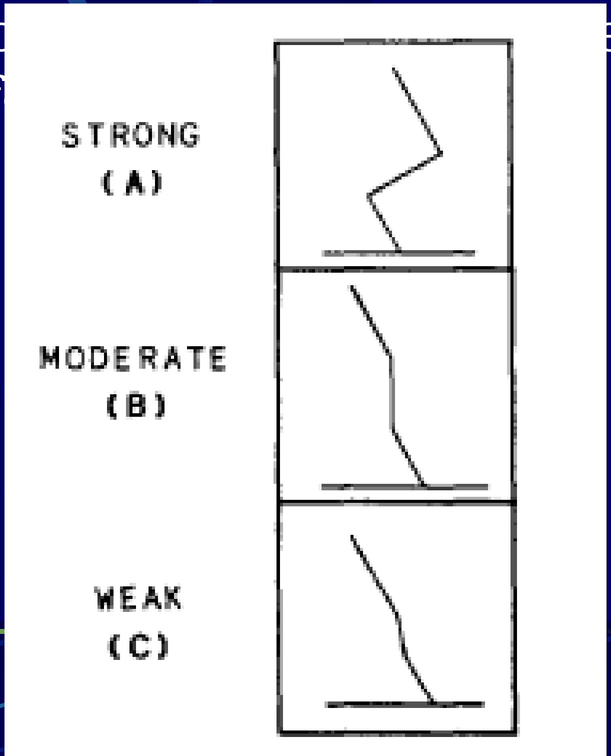
If any doubt exists as to the probable intensity of icing occurring, you may use the formula for determining LWC and actually evaluate a level or two to find LWC. An LWC value less than 0.68 indicates light icing; between 0.68 and 1.33, moderate icing; and greater than 1.33, severe icing. Remember to determine the mixing ratio values from the frost point temperature—not the dew point temperature. Actual LWC calculations would yield values for actual icing conditions— not the maximum probable icing.

FRONTAL ANALYSIS ON THE SKEW T

An analyzed Skew T, Log P Diagram can be used to determine if a front has passed a station, the strength of a front, the height of a front above a station, and frontal slope.

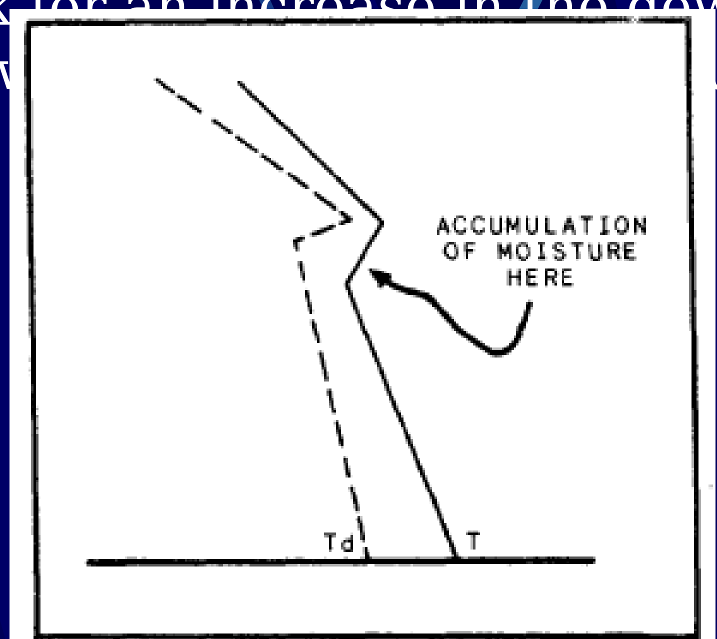
To determine whether a front is above a station, you must examine the temperature and dew point curves. The temperature lapse rate undergoes a change through the frontal zone. It may decrease at a slower rate, becoming more isothermal, or it may increase through the zone, producing an inversion. Figure 6-2-25 illustrates lapse rate changes through frontal zones. Do not look fo e 400 millibars; more often than not, they are f millibars

When there is a significant temperature contrast across a front, the front is classified as strong. Such fronts are marked by an inversion through the frontal zone. Cold fronts usually show a marked temperature inversion. When the temperature contrast across a front is small, it is classified as weak. Such fronts are marked by a temperature lapse rate that is slightly less steep through the



Cold fronts generally show a stronger inversion than warm fronts, and the inversion appears at successively higher levels as the front moves past a station. The reverse is true of warm fronts. Occluded fronts generally show a double inversion when they first form. Later, the temperature contrast across the occlusion lessens and the inversions are wiped out or they fuse.

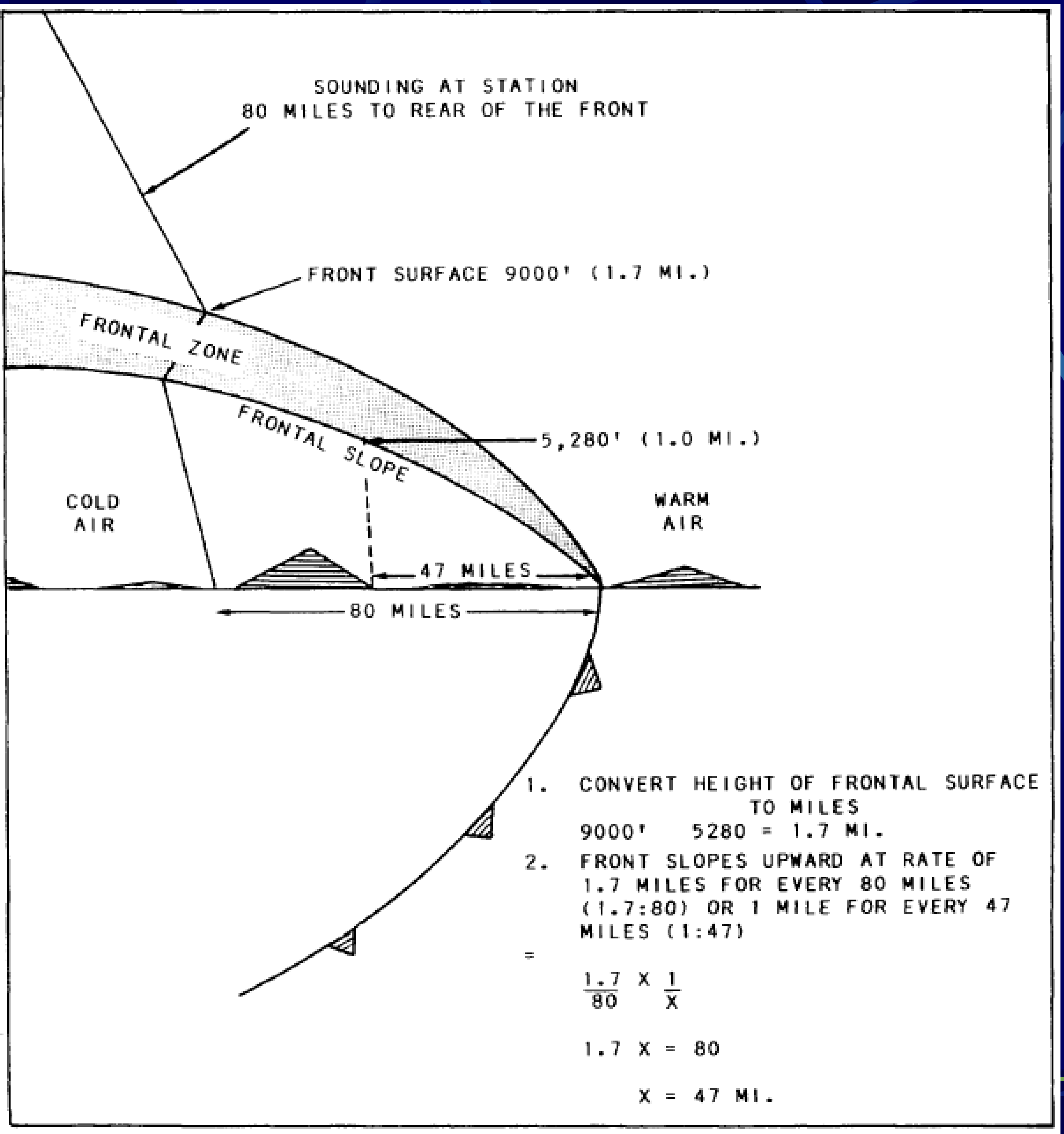
When a front is accompanied by abundant cloudiness and precipitation, look for an increase in the dew point through the frontal zone (a dev [illegible] ure 6-2-26.



Example of a dew-point inversion

When strong fronts are accompanied by little or no precipitation, it is usually due to subsidence occurring in the warm air. Subsidence (sinking air) causes warming and thereby strengthens inversions.

For weather activity to increase at a front, there must be a net upward motion of the warm air mass. Rising air currents bring about cooling, condensation, and saturation. This results in clouds and eventually precipitation. Another determination that can be made using the data on a Skew T is the slope of a front. The slope can be determined when you know the distance to the surface front and the height of the front above the station of interest. The height of a front above a station is determined using the pressure-altitude curve. Normally, the height of the edge of the frontal zone adjacent to the warm air mass is determined. This is the FRONTAL SURFACE. For example, if a fast-moving cold front's surface position is 80 miles east of your station and if the height of the frontal surface, as determined from the Skew T, is 9,000 feet above your station, you can determine the slope of the front using simple mathematics. First, convert the height of the front above the surface (9,000 feet) into miles by dividing 9,000 feet by 5,280 feet (the equivalent of 1 mile). You should get 1.7 miles (rounded off). This is the height of the frontal surface 80 miles to the rear of the surface position. From the surface position, you now know that the front rises at the rate of 1.7 miles for each 80 miles of horizontal distance, or as expressed in ratio form, 1.7:80. The horizontal distance to the point where the frontal surface is 1 mile above the surface is 47 miles. This is



Determination of frontal slope.

OUTLINE

Skew T parameters
Dry adiabats
Saturation adiabats
Saturation mixing ratio
Thickness scale
Contrail formation curves
U.S. Standard Atmosphere
Computation of derived measurements
Potential temperature
Frost point temperature
Saturation mixing ratio
Actual mixing ratio
Relative humidity
Wet-bulb temperature
Wet-bulb potential temperature
Virtual temperature
Layer thickness
Freezing level
Temperature computations
Maximum temperature
Minimum temperature
Computation of cloud formation parameters on the Skew T
Lifting condensation level (LCL)
Convective condensation level (CCL)
Mixing condensation level (MCL)
Level of free convection (LFC)
Positive energy area (PEA) and negative energy area (NEA)
Equilibrium level (EL)